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Guides to Pollution Prevention
The Printed Circuit Board Manufacturing Industry

Jacobs Engineering Group, Inc., Pasadena, CA

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The Printed Circuit Board Manufacturing Industry

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16. ABSTRACT

This guide identifies and analyzes waste minimization methodologies appropriate for the printed circuit board manufacturing industry. The wastes resulting from printed circuit board manufacturing are associated with five types of processes: cleaning and surface preparation; catalyst application and electroless plating; pattern printing and masking; electroplating; and etching. The wastes themselves include airborne particulates, spent acids and alkaline solutions, spent solvents, spent plating baths, waste rinsewater, and other wastes. The guide also presents a set of detailed waste minimization assessment worksheets suitable for use by shop managers and engineers, or by outside consultants, to formulate a waste minimization strategy for the particular plant. Finally, case histories of waste minimization assessments performed at three plants are given.

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GUIDES TO POLLUTION PREVENTION:
The Printed Circuit Board Manufacturing Industry

RISK REDUCTION ENGINEERING LABORATORY
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NOTICE

This guide has been subjected to U.S. Environmental Protection Agency's peer and administrative review and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. This document is intended as advisory guidance only to printed circuit board manufacturers in developing approaches for pollution prevention. Compliance with environmental and occupational safety and health laws is the responsibility of each individual business and is not the focus of this document.

Worksheets are provided for conducting waste minimization assessments of circuit board manufacturing facilities. Users are encouraged to duplicate portions of this publication as needed to implement a waste minimization program.

FOREWORD

This guide identifies and analyzes waste minimization methodoligies appropriate for the printed circuit board manufacturing industry. The wastes resulting from printed circuit board manufacturing are associated with five types of processes: cleaning and surface preparation; catalyst application and electroless plating; pattern printing and masking; electroplating; and etching. The wastes include airborne particulates, spent plating baths, waste rinsewater, and other wastes.

Waste minimization assessment worksheets are contained with in this guide to be of use to shop managers and engineers, or consultants in formulating a waste minimization strategy for a particular plant. Case histories of waste minimzation assessments performed at three plants are presented.

ACKNOWLEDGMENTS

This guide is based in part on waste minimization assessments conducted by Planning Research Corporation, San Jose, California for the California Department of Health Services (DHS). Contributors to these assessments include: David Leu, Benjamin Fries, Kim Wilhelm, and Jan Radimsky of the Alternative Technology Section of DHS. Much of the information in this guide that provides a national perspective on the issues of waste generation and minimization for circuit board manufacturers was provided originally to the U.S. Environmental Protection Agency by Versar, Inc. and Jacobs Engineering Group Inc. in *Waste Minimization-Issues and Options, Volume II*, Report No. PB87-114369 (1986). Jacobs Engineering Group Inc. edited and developed this version of the waste minimization assessment guide, under subcontract to Radian Corporation (USEPA Contract 68-02-4286).

Lisa M. Brown of the U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, was the project officer responsible for the preparation and review of this document. Other contributors and reviewers include: Bonnie Blam, IBM corporation; Bonnie Gariepy and Terrence J. McManus, Intel Corporation; and Arthur H. Purcell, UCLA Engineering Research Center.

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SECTION 1
INTRODUCTION

This guide is designed to provide printed circuit board manufacturers with waste minimization options appropriate for this industry. It also provides worksheets designed to be used for a waste minimization assessment of a manufacturing facility, to develop an understanding of the facility's waste generating processes and to suggest ways that the waste may be reduced.

The worksheets and the list of waste minimization options were developed through assessments of three Santa Clara area prototype circuit board manufacturing shops. The assessments were commissioned by the California Department of Health Services (CDHS 1987). The firms' operations, manufacturing processes, and waste generation and management practices were surveyed, and their existing and potential waste minimization options were characterized. Economic analyses were performed on selected options.

Today's industry is faced with the major technological challenge of identifying ways to effectively manage hazardous waste. Technologies designed to treat and dispose of wastes are no longer the optimal strategy for handling these wastes for two major reasons. First, the potential liabilities associated with handling and disposing of hazardous wastes have increased significantly. Second, restrictions placed on land disposal of hazardous wastes have caused considerable increases in waste disposal costs. The economic impact of these changes is causing industry to explore alternatives to treatment and disposal technologies.

Waste minimization is a policy specifically mandated by the U.S. Congress in the 1984 Hazardous and Solid Wastes Amendments to the Resource Conservation and Recovery Act (RCRA). As the federal agency responsible for writing regulations under RCRA, the U.S. Environmental Protection Agency (EPA) has an interest in ensuring that new methods and approaches are developed for minimizing hazardous waste and that such information is made available to the industries concerned. This guide is one of the approaches EPA is using to provide industry-specific information about hazardous waste minimization. The options and procedures outlined can also be used in efforts to minimize other wastes generated in a facility.

EPA has also developed a general manual for waste minimization in industry. The *Waste Minimization Opportunity Assessment Manual* (USEPA 1988) tells how to conduct a waste minimization assessment and develop options for reducing hazardous waste generation at a facility. It explains the management strategies needed to incorporate waste minimization into company policies and structure, how to establish a company-wide waste minimization program, conduct assessments, implement options, and make the program an on-going one. The elements of waste minimization assessment are explained in the next section of this document, the Overview.

In the following sections of this manual you will find:

- An overview of the printed circuit board (PC board) manufacturing industry and the processes used by the industry (Section Two);
- Waste minimization options for printed circuit board manufacturers (Section Three);
- Waste Minimization Assessment Guidelines and Worksheets (Section Four)
- An Appendix, containing:
  - Case studies of waste generation and waste minimization practices of three printed circuit board manufacturers;
  - Where to get help: additional sources of information.

Overview of Waste Minimization Assessment

In the working definition used by EPA, waste minimization consists of source reduction (preventing the generation of waste at its point of origin) and recycling. Of the two approaches, source reduction is usually considered preferable to recycling from an environmental perspective. Treatment of hazardous waste is considered an approach to waste minimization by some states but not by others, and is not addressed in this guide.

A Waste Minimization Opportunity Assessment (WMOA), sometimes called a waste minimization audit, is

a systematic procedure for identifying ways to reduce or eliminate waste. The steps involved in conducting a waste minimization assessment are outlined in Figure 1 and presented in more detail in the next paragraphs. Briefly, the assessment consists of a careful review of a plant's operations and waste streams and the selection of specific areas to assess. After a particular waste stream or area is established as the WMOA focus, a number of options with the potential to minimize waste are developed and screened. The technical and economic feasibility of the selected options are then evaluated. Finally, the most promising options are selected for implementation.

To determine whether a WMOA would be useful in your circumstances, you should first read this section describing the aims and essentials of the assessment process. For more detailed information on conducting a WMOA, consult The Waste Minimization Opportunity Assessment Manual.

The four phases of a waste minimization opportunity assessment are:

- Planning and organization
- Assessment phase
- Feasibility analysis phase
- Implementation

PLANNING AND ORGANIZATION

Essential elements of planning and organization for a waste minimization program are: getting management commitment for the program; setting waste minimization goals; and organizing an assessment program task force. The importance of these initial steps cannot be over estimated.

ASSESSMENT PHASE

The assessment phase involves a number of steps:

- Collect process and facility data
- Prioritize and select assessment targets
- Select assessment team
- Review data and inspect site
- Generate options
- Screen and select options for feasibility study

Collect process and facility data. The waste streams at a facility should be identified and characterized. Information about waste streams may be available on hazardous waste manifests, waste profile sheets, routine sampling programs and other sources.

Developing a basic understanding of the processes that generate waste at a facility is essential to the WMOA process. Flow diagrams should be prepared to identify the quantity, types and rates of waste generating processes. Also, preparing material balances for various processes can be useful in tracking various process components and identifying losses or emissions that may have been unaccounted for previously.

Prioritize and select assessment targets. Ideally, all waste streams in a facility should be evaluated for potential waste minimization opportunities. With limited resources, however, a plant manager may need to concentrate waste minimization efforts in a specific area. Such considerations as quantity of waste, hazardous properties of the waste, waste disposal restrictions, regulations, safety of employees, economics, cost of disposal, and other characteristics need to be evaluated in selecting a target stream.

Select assessment team. The team should include people with direct responsibility and knowledge of the particular waste stream or area of the plant, including machine operators and maintenance personnel.

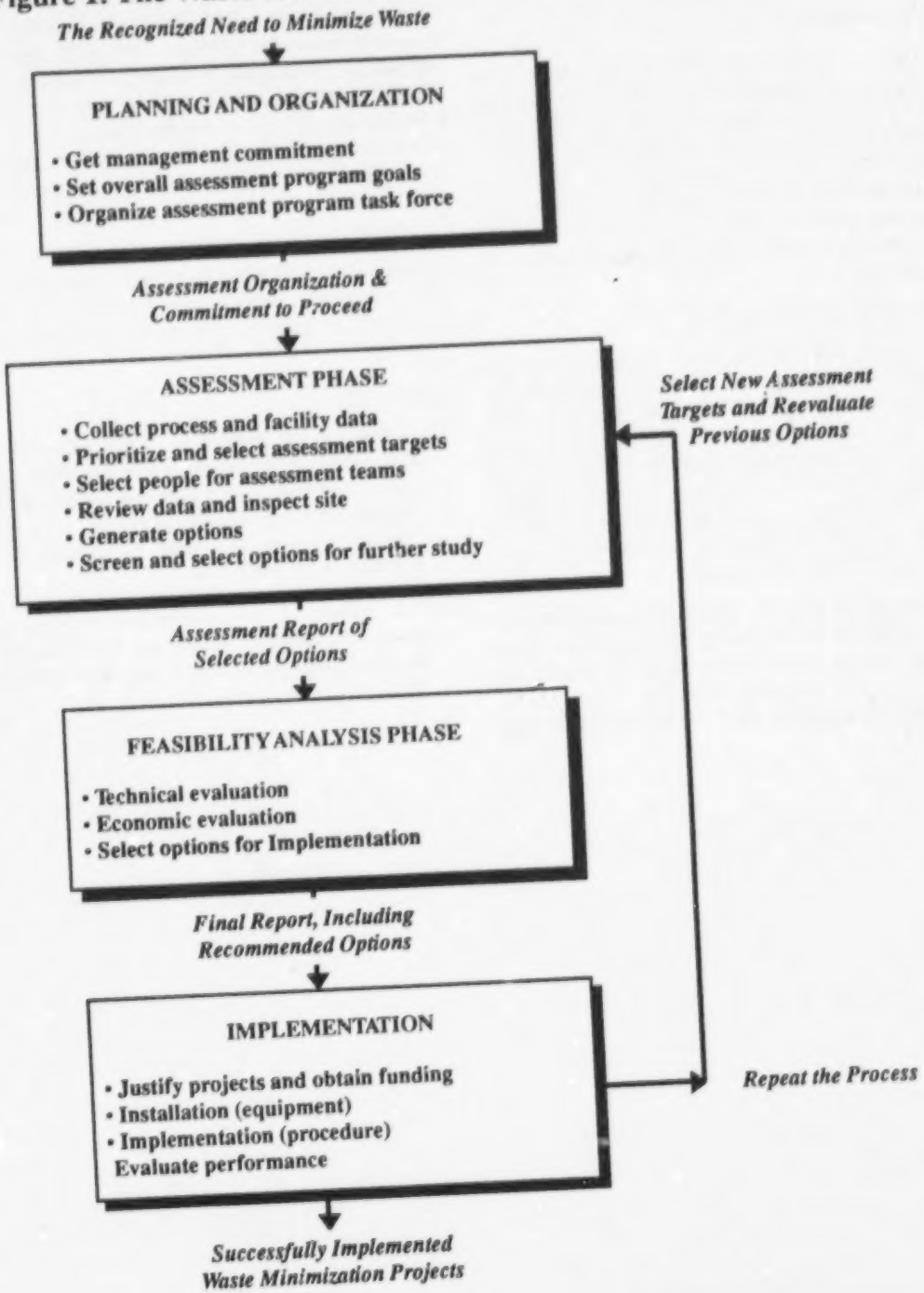
Review data and inspect site. The assessment team evaluates process data in advance of the inspection. The inspection should follow the target process from the point where raw materials enter the facility to the points where products and wastes leave. The team should identify the suspected sources of waste. This may include the production process; maintenance operations; and storage areas for raw materials, finished product, and work in progress. The inspection may result in the formation of preliminary conclusions about waste minimization opportunities. Full confirmation of these conclusions may require additional data collection, analysis, and/or site visits.

Generate options. The objective of this step is to generate a comprehensive set of waste minimization options for further consideration. Since technical and economic concerns will be considered in the later feasibility step, no options are ruled out at this time. Information from the site inspection, as well as trade associations, government agencies, technical and trade reports, equipment vendors, consultants, and plant engineers and operators may serve as sources of ideas for waste minimization options.

Both source reduction and recycling options should be considered. Source reduction may be accomplished through:

- Good operating practices
- Technology changes
- Input material changes

Figure 1. The Waste Minimization Assessment Procedure


The Recognized Need to Minimize Waste
PLANNING AND ORGANIZATION
• Get management commitment
• Set overall assessment program goals
• Organize assessment program task force
Assessment Organization & Commitment to Proceed
ASSESSMENT PHASE
• Collect process and facility data
• Prioritize and select assessment targets
• Select people for assessment teams
• Review data and inspect site
• Generate options
• Screen and select options for further study
Select New Assessment Targets and Reevaluate Previous Options
Assessment Report of Selected Options
FEASIBILITY ANALYSIS PHASE
• Technical evaluation
• Economic evaluation
• Select options for Implementation
Final Report, Including Recommended Options
IMPLEMENTATION
• Justify projects and obtain funding
• Installation (equipment)
• Implementation (procedure)
Evaluate performance
Repeat the Process
Successfully Implemented Waste Minimization Projects

- Product changes

Recycling includes:

- Use and reuse of waste
- Reclamation

Screen and select options for further study. This screening process is intended to select the most promising options for full technical and economic feasibility study. Through either an informal review or a quantitative decision-making process, options that appear marginal, impractical or inferior are eliminated from consideration. Some of the criteria used in screening options include impacts on product quality; employee safety; and environmental impacts of the alternatives.

FEASIBILITY ANALYSIS

An option must be shown to be technically and economically feasible in order to merit serious consideration for adoption at a facility. A technical evaluation determines whether a proposed option will work in a specific application. Both process and equipment changes need to be assessed for their overall effects on waste quantity, toxicity, and product quality. Also, any new products developed through process and/or raw material changes need to be tested for market acceptance.

An economic evaluation is carried out using standard measures of profitability, such as payback period, return on investment, and net present value. As in any project, the cost elements of a waste minimization project can be broken down into capital costs and economic costs. Savings and changes in revenue also need to be considered.

IMPLEMENTATION

An option that passes both technical and economic feasibility reviews should then be implemented at a facility. It is then up to the WMOA team, with management support, to continue the process of tracking wastes and identifying opportunities for waste minimization throughout a facility and by way of periodic reassessments. Either such ongoing reassessments or an initial investigation of waste minimization opportunities can be conducted using this manual.

While it is difficult to quantify the future liability reduction that could result from implementing an option, this is an important factor in choosing a particular strategy, and should at least be discussed qualitatively in the evaluation.

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SECTION 2
PRINTED CIRCUIT BOARD MANUFACTURING INDUSTRY PROFILE

Manufacturers of printed circuit boards (PC boards) are included as part of the electronic component manufacturing industry. As of 1984, the printed circuit board manufacturing industry consisted of a total of 585 plants with an employment of 435,100 (NCO 1984). Industry personnel indicate that the actual number of plants may be closer to 1,000 (USEPA 1986).

The industry consists of large facilities totally dedicated to printed circuit boards, large and small captive facilities, small job shops doing contract work, and specialty shops doing low-volume and high-volume precision work. Approximately half of the printed circuit boards produced are by independent producers, while the rest are by captive producers. Over 65 percent of all printed circuit board manufacturing sites are located in the northeastern states and in California (NCO 1984).

The printed circuit board manufacturers visited as a part of this study are all considered small. Generally, these small companies can be characterized as those that produce up to 3,000 to 5,000 square feet of processed board each month and require approximately 8,000 to 10,000 square feet of building space. Large companies can be characterized as those that produce or 30,000 to 50,000 square feet per month.

Products and Their Use

Printed circuit boards can be classified into three basic types: single-sided, double-sided, and multi-layered. The total board production in 1983 was 14 million square meters (PEI 1983). Double-sided boards accounted for about 55 percent of the printed circuit boards produced, while multi-layer board production made up 26 percent (PEI 1983). The type of board produced depends on the spatial and density requirement, and on the complexity of the circuitry. Printed circuit boards are used mainly in the production of business machines, computers, communication equipment, control equipment and home entertainment equipment.

Raw Materials

The following raw materials are used by the industry (Stintson 1983, PEI 1983, Cox and Mills 1985):

Board materials	glass-epoxy, ceramics, plastic, phenolic paper, copper foil
Cleaners	sulfuric acid, fluoroacetic acid, hydrofluoric acid, sodium hydroxide, potassium hydroxide, trichloroethylene, 1,1,1-trichloroethane, perchloroethylene, methylene chloride
Etchants	sulfuric and chromic acid, ammonium persulfate, hydrogen peroxide, cupric chloride, ferric chloride, alkaline ammonia
Catalysts	stannous chloride, palladium chloride
Electroless copper bath	copper sulfate, sodium carbonate, sodium gluconate, Rochelle salts, sodium hydroxide, formaldehyde
Screen Screen ink	silk, polyester, stainless steel composed of oil, cellulose, asphalt, vinyl or other resins
Resists	polyvinyl cinnamate, allyl ester, resins, isoprenoid resins, methacrylate derivatives, poly-olefin sulfones
Sensitizers	thiazoline compounds, azido compounds, nitro compounds, nitro aniline derivatives, anthones, quinones, diphenyls, azides, xanthone, benzil
Resist solvents	ortho-xylene, meta-xylene, para-xylene, toluene, benzene, chlorobenzene, cellosolve and cellosolve acetate, butyl acetate, 1,1,1-trichoroethane, acetone, methyl ethyl ketone, methyl isobutyl ketone
Electroplating baths	copper pyrophosphate solution, acid-copper sulfate solution, acid-copper fluoroborate solution, tin-lead, gold, and nickel plating solutions

Resist stripping	sulfuric-dichromate, ammoniacal hydrogen peroxide, solutions metachloroperbenzoic acid, methylene chloride, methyl alcohol, furfural, phenol, ketones, chlorinated hydrocarbons, non-chlorinated organic solvents, sodium hydroxide

Process Description

Printed circuit (PC) boards, also called printed wiring boards, consist of patterns of conductive material formed onto a non-conductive base. The conductor is generally copper, although aluminum, chrome, nickel and other metals have been used. The metal is fixed to the base through use of adhesives, pressure/heat bonding, and sometimes screws. Base materials include pressed epoxy paper, phenolic, epoxy glass resins, teflon-glass, and many other materials.

There are three common types of PC boards: single-sided, double-sided, and multilayer. Single sided boards are those with a conductive pattern on one side only. Double-sided boards have conductive patterns on both faces. Multilayer boards consist of alternating layers of conductor and insulating material, bonded together. The conductors are connected together through plated-through holes.

Production methods that have been employed by the industry to produce printed circuit boards include subtractive processes and additive processes. Detailed descriptions of the process sequences are given elsewhere (Yapoujian 1982, Coombs 1979, USEPA 1979, PEI 1983). Because of the limitations of the additive processes, the subtractive method is currently the one most widely used, although it can produce more metal wastes than additive methods. The subtractive method is briefly described below for double-sided panels. Most of the operations shown are also common to the production of other types of printed circuit boards such as single-sided or multi-layered boards.

The conventional subtractive process employs a copper-clad laminate board composed of a non-conductive material such as glass epoxy or plastic. Printed circuit board manufacturers often purchase panels of board that are already copper clad from independent laminators. The manufacturing process consists of the following operations:

Board preparation - The process sequence begins with a baking step to ensure that the copper laminated boards are completely cured. Holes for the components are then drilled through stacks of boards or panels, often four layers thick. The drilling operation results in burrs being formed on one or both sides of the panel. These are removed mechanically through sanding and deburring steps to create an even surface.

Electroless copper plating - The smooth copper-clad board is subsequently electroless- plated with copper to provide a conducting layer through the drilled holes for circuit connections between the copper-clad board surfaces. Electroless plating involves the catalytic reduction of a metallic ion in an aqueous solution containing a reducing agent, resulting in deposition without the use of external electrical energy. The circuit board must be thoroughly cleaned before it is electroless-plated.

Materials typically used in the operation, that appear in the waste streams, include:

- Abrasive and alkaline cleaning compounds
- Ammonium persulfate or peroxide-sulfuric acid etchant, for removing the oxidation inhibitor in the copper foil
- Tin and palladium catalyst
- Cupric chloride or copper sulfate plating bath containing formaldehyde or hypophosphate reducing agents, and amino acid, carboxylic acid, hydroxy acid, or amine chelating agents
- Rinsewaters

Pattern printing and masking - Electroless plating with copper provides a uniform but very thin conducting layer over the entire surface, that has little mechanical strength. It is used initially, to deposit metal on non-conducting surfaces such as inside the holes. Electroplating is required to build up the thickness and strength of the conducting layers.

Pattern plating is one method of buiding up conducting layer thickness, and is the most common type of subtractive process used. It consists of electroplating only the insides of the holes and the circuit patterns. A layer of resist is deposited, using screen or photolithography techniques, in areas where electroplated conducting material is not desired. The layer of resist on these areas is later stripped off, and the copper foil is etched away.

The area where the resist has not been deposited constitutes the circuit pattern. These areas receive several electrodeposition layers. Tin/lead plating is one of the layers deposited, and it functions as another resist layer, allowing copper foil in the non-circuit areas to be etched away without the circuit pattern being damaged. The circuit pattern then receives final electroplated layers of metals such as nickel and gold. Chemicals used for these processes include:

- Photo-sensitive inks (for silk screening circuit patterns onto the board)
- Resists composed of epoxy vinyl polymers, halogenated aromatics, methacrylates, and/or polyolefin sulfones
- Alkaline cleaners to remove residuals from pattern developing operations
- Acid dips to remove oxides
- Electroplating solutions typically containing copper, tin/lead, nickel and gold salts, cyanide, sulfate, pyrophosphate, and fluoroborate compounds
- Etchants such as peroxide-sulfuric acid, sodium persulfate, ferric or cupric chloride, and chromic acid

Panel plating methods of PC board manufacture differ from pattern plating in that the entire board is electroplated with copper, including the holes, after which the non-circuit areas are etched away. Because of the additional copper deposited, panel plating can produce more metal wastes.

The fully additive method differs from the subtractive method described above in that it involves deposition of plating material onto the board only in the pattern dictated by the circuit, and does not require removal of the metal already deposited. The process begins with an unclad board. Plating resist is then applied onto the board in non-circuit areas. Electroless copper is subsequently deposited to build up the circuit to the desired thickness. Since the board doesn't initially have any copper in non-circuit areas, a copper etching step is thus eliminated, as well as much of the metal wastes.

Waste Description

There are five principal operations common to the production of all types of printed circuit boards. These include:

- Cleaning and surface preparation
- Catalyst application and electroless plating
- Pattern printing and masking
- Electroplating
- Etching

Typical waste streams generated from the unit operations in the printed circuit board manufacturing industry are listed in Table 1.

Airborne particulates generated from the cutting, sanding, routing, drilling, beveling, and slotting operations during board preparations are normally collected and separated using baghouse and cyclone separators. They are then disposed of, along with other solid wastes at landfills.

Acid fumes from acid cleaning and organic vapors from vapor degreasing are usually not contaminated with other materials, and therefore are often kept separate for subsequent treatment. The acid fume air stream is collected via chemical fume hoods and sent to a scrubber where it is removed with water. The scrubbed air then passes on to the atmosphere, and the absorbing solution is neutralized along with other acidic waste streams. Similarly, organic fumes are often collected and passed through a bed of activated carbon. The carbon bed is then regenerated with steam. In many cases, the regenerative vapor is condensed and the condensate containing water and solvents is drummed and sent for offsite treatments. In a few cases, the regenerative vapor is combusted in a closed fumes burner.

The spent acid and alkaline solutions from the cleaning steps are either contract hauled for off-site disposal or neutralized and discharged to the sewer. Spent chlorinated organic solvents are often gravity separated, and are recovered in-house or hauled away for reclaiming.

The remaining majority of the wastes produced are liquid waste streams containing suspended solids, metals, fluoride, phosphorus, cyanide, and chelating agents. Low pH values often characterize the wastes due to acid cleaning operations. The liquid wastes may be controlled using end-of-pipe treatment systems, or a combination of in-line treatment and separate treatment of segregated waste streams. A traditional treatment system for the wastes generated is often based on pH adjustment and the addition of chemicals that will react with the soluble pollutants to precipitate out the dissolved contaminants in a form such as metal hydroxide or sulfate. The solid particles are removed as a wet sludge by filtration or flotation, and the water is discharged to the sewer. The diluted sludge is usually thickened before dumping into landfills. Recent improvements in in-line treatment technologies such as reverse osmosis, ion exchange, membrane filtration, and advanced rinsing techniques increase the possibility for the recovery and reuse of water and metallic resources.

Table 1. Waste Streams from Printed Circuit Board Manufacturing

Waste Source	Waste Stream Description	Waste Stream Composition
Cleaning/Surface preparation	1. Airborne particulates 2. Acid fumes/organic vapors 3. Spent acid/alkaline solution 4. Spent halogenated solvents 5. Waste rinse water	Board materials, sanding materials, metals, fluoride, acids, halogenated solvents, alkali.
Catalyst application/ Electroless plating	1.Spent electroless copper bath 2. Spent catalyst solution 3. Spent acid solution 4. Waste rinse water	Acids, stannic oxide, palladium, complexed metals, chelating agents.
Pattern printing/masking	1. Spent developing solution 2. Spent resist removal solution 3. Spent acid solution 4. Waste rinse water	Vinyl polymers, chlorinated hydrocarbons, organic solvents, alkali.
Electroplating	1. Spent plating bath 2. Waste rinse water	Copper, nickel, tin, tin/lead, gold, fluoride, cyanide, sulfate.
Etching	1. Spent etchant 2. Waste rinse water	Ammonia, chromium, copper, iron, acids.

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SECTION 3
WASTE MINIMIZATION OPTIONS FOR PRINTED CIRCUIT BOARD MANUFACTURERS

This section discusses recommended waste minimization methods for printed circuit board manufacturers. These methods come from accounts published in the open literature and through industry contacts. The primary waste streams associated with manufacturing are listed in Table 2 along with recommended control methods. Many control measures associated with photoprocessing and cleaning wastes are not discussed in this report. The reader is referred to the appropriate reference material for information regarding these waste streams (USEPA 1989, USEPA 1990, USEPA 1986, CDHS 1986).

The waste minimization methods listed in Table 2 can be classified generally as source reduction, or recycling. Source reduction can be achieved through material or product substitution, process or equipment modification, or better operating practices. Recycling can include recovery of part of the waste stream or reuse of all of it, and can be performed on-site or off-site.

Better operating practices are procedural or institutional policies that result in a reduction of waste. They include:

- Waste stream segregation
- Personnel practices
  - Management initiatives
  - Employee training
  - Employee incentives
- Procedural measures
  - Documentation
  - Material handling and storage
  - Material tracking and inventory control
  - Scheduling
- Loss prevention practices
  - Spill prevention
  - Preventive maintenance
  - Emergency preparedness
- Accounting practices
  - Apportion waste management costs to departments that generate the waste

Better operating practices apply to all waste streams. In addition, specific better operating practices that apply to certain waste streams are identified in the appropriate sections that follow.

Product Substitution

While not under the control of most printed circuit board manufacturers, improvements in the techniques used in the packaging of microchips can result in a decrease of waste associated with printed circuit board manufacturing. Two new techniques include:

Increased use of surface mount technology. Presently, the dual-in-line package (DIP) accounts for 80% of all packaging of integrated circuits (Bowlby 1985). More efficient packages, however, are being developed which utilize a relatively new method of attaching packages to printed circuit boards. One important method is called surface mount technology (SMT). The use of SMT instead of the conventional through-hole insertion mounting allows for closer contact areas of chip leads, and therefore reduces the size of printed circuit boards required for a given number of packages or DIPS. For a fixed number of packages, the printed circuit board needs to be only 35 percent to 60 percent as large as a printed circuit board designed for the old style package (Bowlby 1985). As the metal area on which cleaning, plating and photoresist operations are performed is decreased, the wastes associated with these operations can also be reduced. At present, however, SMT uses considerably higher quantities of chlorofluorocarbons for degreasing than through-hole mounting. CFC-113 is one of the major degreasing agents in current use. Because of the danger that some chlorofluorocarbons present to the atmospheric ozone layer, the overall environmental risks of SMT must be carefully examined, and alternative degreasing solvents identified, before replacing through-hole technology with SMT.

Use of injection molded substrate and additive plating. The development of high-temperature, high-performance thermoplastics has introduced the use of injection molding

Table 2. Waste Minimization Methods for the Printed Circuit Board Industry

Operation	Waste Minimization Method
PC Board Manufacture	Product Substitution: Surface mount technology Injection molded substrate and additive plating
Cleaning and Surface Preparation	Materials substitution: Use abrasives Use non-chelated cleaners
	Increase efficiency of process: Extend bath life, improve rinse efficiency, countercurrent cleaning
	Recycle/reuse: Recycle/reuse cleaners and rinses
Pattern Printing and Masking	Reduce hazardous nature of process: Aqueous processable resist Screen printing versus photolithography Dry photoresist removal
	Recycle/reuse: Recycle/reuse photoresist stripper
Electroplating and Electroless Plating	Eliminate process: Mechanical board production
	Materials substitution: Non-cyanide baths Non-cyanide stress relievers
	Extend bath life: reduce drag-in Proper rack design/maintenance, better precleaning/rinsing, use of demineralized water as makeup, proper storage methods
	Extend bath life: reduce drag-out Minimize bath chemical concentration, increase bath temperature, use wetting agents, proper positioning on rack, slow withdrawal and ample drainage, computerized/automated systems, recover drag-out, drain boards
	Extend bath life: maintain bath solution quality Monitor solution activity. Control temperature. Mechanical agitation. Continuous filtration/ carbon treatment. Impurity removal
	Improve rinse efficiency: Closed-circuit rinses. Spray rinses. Fog nozzles. Increased agitation. Countercurrent rinsing. Proper equipment design/operatnon. Deionized water use.
	Recovery/reuse: Segregate streams. Recover metal values
Etching	Eliminate process: Differnetial plating
	Materials substitution: Non-chelated etchants. Non-chrome etchants

Table 2. Waste Minimization Methods for the Printed Circuit Board Industry (continued)

Operation	Waste Minimization Method
Etching (continued)	Increase efficiency: Use thinner copper cladding. Pattern vs. panel plating. Additive vs. subtractive method.
	Reuse/recycle:
	Reuse/recycle etchants
Wastewater Treatment	Reduce hazardous nature: Alternative treatment chemicals that generate less sludge Use of ion exchange and activated carbon for recycling wastewater
	Reuse/recycle: Waste stream segregation

into the manufacturing of printed circuit boards. In this process, heated liquid polymer is injected under high pressure into precision molds. Since the molded substrates are unclad, semi-additive or fully additive plating is used to produce metalized conductor patterns (Engelmaier and Frisch 1982). Injection molding, coupled with a fast-rate electrodeposition (FRED) technique, such as that developed by Battelle (LWVM 1985), can be used to manufacture complex three-dimensional printed circuit boards with possible reduction in hazardous waste generation due to the elimination of spent toxic etchants.

Cleaning and Surface Preparation

As mentioned in the introduction, the reader should refer to the appropriate reference material (USEPA 1989, CDHS 1986) for information regarding the reduction of waste associated with parts cleaning. Information is provided below on: abrasive cleaning; use of non-chelated cleaning chemicals; extending bath life and improving rinse efficiency; use of countercurrent cleaning arrangements; and reuse/recycle of cleaning agents and rinse water.

USE ABRASIVE INSTEAD OF AQUEOUS CLEANING

Mechanical cleaning methods offer an alternative to aqueous techniques and generate less hazardous waste; however, these methods can only be employed before electronic components have been added to the boards. Abrasive blast cleaning uses plastic, ceramic, or harder media such as aluminum oxide to remove oxidation layers, old plating, paint and burrs from workpieces, and to create a smooth surface. The aim is to select a blast medium that is harder than the layer to be stripped, but softer than the substrate, in order to prevent damage to the part. Abrasives can also be used in vibratory cleaning (in which parts are immersed in a vibrating tank containing abrasive material and water), in tumbling barrels, or applied via a buffing wheel. More information on abrasive cleaning, particularly tumbling barrels and vibratory cleaning, can be found in Durney (1984) and ASM (1987).

USE NON-CHELATED CLEANING CHEMICALS

The use of non-chelate process chemicals instead of chelated chemical baths can reduce hazardous waste generation. Chelators are employed in chemical process baths to allow metal ions to remain in solution beyond their normal solubility limit. This enhances cleaning, metal etching, and selective electroless plating (Couture 1984). Once the chelating compounds enter the waste stream, they inhibit the precipitation of metals, and additional treatment chemicals must be used. These treatment chemicals end up in the sludge and contribute to the volume of hazardous waste sludge.

Ferrous sulfate is a common reducing agent used to treat wastewaters that contain chelators. The ferrous sulfate breaks down the complex ion structures to allow metals to precipitate. However, the iron added to the treatment process also precipitates as a metal hydroxide. Since enough ferrous sulfate is usually added to the wastewater to achieve an iron to metal ratio of 8:1, a significant additional volume of sludge is generated (Couture 1984). One printed circuit board manufacturer visited during the audit study used ferrous sulfate to break down chelators prior to metals precipitation. The iron present in the resultant sludge contributed approximately 32 percent of the total dry weight of the sludge.

Common chelators used in printed circuit board manufacturing chemicals include ferrocyanide,

ethylenediaminetetraacetic acid (EDTA), phosphates, and ammonia (Foggia 1987). Chelating agents are commonly found in cleaning chemicals and etchants. Non-chelate alkaline cleaners are available; however, laboratory tests have shown that some of these products still have the ability to chelate metals (Couture 1984).

In addition to using non-chelated chemistries, the use of mild chelators can also reduce the need for additional treatment of wastewaters. Mild chelators are less difficult to break down. Therefore, metals can be precipitated out of solution during treatment without using the volume of treatment chemicals that is often necessary with strong chelators. For example, EDTA is a mild chelator that only requires lowering the pH to below 3.0 to allow metals to precipitate (Foggia 1987).

One disadvantage of using non-chelated process baths is that they usually require continuous filtration to remove the solids that form in the bath. The costs of these filter systems range from approximately $400 to $1,000 for each tank using a non-chelated process chemistry. These systems generally have a 1 to 5 micron filter with a control pump that can filter the tank contents once or twice each hour (Foggia 1987). In addition to the purchase and setup costs, filter replacement and maintenance costs are incurred when this system is used.

EXTEND BATH LIFE AND IMPROVE RINSE EFFICIENCY

This method applies to nearly any tank of processing solution used in the facility. See the discussion of electroplating waste reduction methods for detailed information.

USE COUNTERCURRENT CLEANING ARRANGEMENT

A common hazardous waste stream generated by printed circuit board manufacturers is waste nitric acid from the cleaning of electroplating workpiece racks. Typically, racks are placed in a nitric acid bath to clean off the plated copper. When the copper content in the bath gets too high to effectively clean the racks, the nitric acid is containerized for disposal. Use of a cascade cleaning system can significantly reduce nitric acid waste generation.

During the audits, one small printed circuit board manufacturer who operated a five tank plating rack cleaning line generated approximately 15 gallons of waste nitric acid in 6 months compared to another small company that used a single tank for cleaning racks and generated approximately 60 gallons each month. Both companies operate similar size process lines, and are considered small printed circuit board manufacturers (both estimated their printed circuit board production to be 3,000 square feet per month). Assuming that waste disposal for the spent nitric acid is $50 per 55-gallon drum and the cost of technical grade nitric acid is approximately $3.50 per gallon, the differential operating costs are $3042 per year (excluding differences in labor-increased rack handling versus decreased waste handling). The total cost of adding four additional tanks to the one-cleaning-tank line would be $1620.

REUSE/RECYCLE OF CLEANING AGENTS

Peroxide/sulfuric acid solution is used as a mild etchant for cleaning copper and removing oxides prior to plating. When the solution is brought off-line and cooled, the copper crystallizes as copper sulfate. The supernatant can then be returned to the tank, replenished with oxidizers, and reused. The copper sulfate crystals can be used as copper electroplating bath makeup (Couture 1984). The practice is only advisable, however, if the crystals are first dissolved into solution and treated with activated carbon to remove the organics. Otherwise, the organics present in the crystals could ruin the plating bath.

In addition to recovering metals from the spent bath, spent acid can be regenerated by means of ion exchange (Basta 1983). Eco-Tec Ltd., in Ontario, Canada, markets an acid purification system that employs a proprietary resin that recovers mineral acids. The metals are recovered in a concentrated (but still dissolved) form. The concentrated metals can then be recovered by electrolytic means.

Ion exchange is employed by Modine Manufacturing, in Trenton, Mo., to treat copper-contaminated sulfuric acid/hydrogen peroxide solution which is used to brighten brass (Basta 1983). Sodium phosphate salts, formed in nickel/copper electroless plating, can be converted into useful hypophosphite salts by ion exchange resins activated with hypophosphorous acid. The use of ion exchange resins for regeneration, however, suffers from the disadvantage of generating additional wastes, such as spent resins and resin regeneration solutions.

REUSE/RECYCLE OF RINSE WATER

After rinse solutions become too contaminated for their original rinse process, they may be useful for other rinse processes. For example, rinses containing high levels of process chemicals can be concentrated through evaporation and returned to the process baths as makeup. Closed-circuit rinsing of this type can dramatically reduce the hazardous chemicals content of the waste stream.

Effluent from a rinse system that follows an acid cleaning bath can be reused as influent water to a rinse system following an alkaline cleaning bath. If both rinse systems require the same flow rate, 50 percent less rinse water would be used to operate them. In addition, using the

effluent from the rinse solution that follows an acid cleaning process as the feed to the rinse system that follows an alkaline cleaning process rinse system can actually improve rinse efficiency for two reasons. First, the chemical diffusion process is accelerated because the concentration of alkaline material at the interface between the drag-out film and the surrounding water is reduced by the neutralization reaction. Second, the neutralization reaction reduces the viscosity of the alkaline drag-out film (USEPA 1982a). One successful example of this technique was observed in a nickel plating process in which the same rinse water stream was used for the rinses following the alkaline cleaning, acid dip, and nickel plating tanks. Instead of having three different rinse streams, only one stream was used, greatly reducing the overall rinse water requirements (USEPA 1983).

Adding acid rinses to alkaline rinses can result in problems, however. Unwanted precipitation of metal hydroxides onto the cleaned workpieces can occur in some instances. Before being implemented, a combined acid and alkaline rinse system must be thoroughly investigated in the particular environment of the process line.

Other rinse water recycling opportunities are also available. Acid cleaning rinse water effluent can be used as rinse water for workpieces that have gone through a mild acid etch process. Effluent from a critical or final rinse operation, which is usually less contaminated than other rinse waters, can be used as influent for rinse operations that do not require high rinse efficiencies. The water from fume scrubbers has been shown to be practical for rinsing in certain cases (Cheremisinoff, Peina, and Ciancia 1976). Spent cooling water or steam condensate can also be employed for rinsing if technically permissible and economically justified. Printed circuit board manufacturers should evaluate the various rinse water requirements for their process lines and configure rinse system arrangements that take advantage of rinse water reuse opportunities.

Pattern Printing and Masking

Many of the source reduction techniques discussed for the photoprocessing industry (USEPA 1988) apply to this phase of printed circuit board manufacturing. Listed below are several techniques that deal with circuit board fabrication.

Use aqueous processable resist instead of solvent processable resist. Aqueous processable resists (such as the Du Pont Riston photopolymer film resists which allow for the use of caustic and carbonates as developer and stripper) can be used in place of solvent processable resists whenever possible to eliminate the generation of toxic spent solvents. Hundred of facilities are now employing these aqueous processable films for the manufacturing of printed circuit boards.

Use screen-printing instead of photolithography to eliminate the need for developers. Screen-printing has conventionally been used only to produce printed circuit boards which require very low resolution in the width and spacing of the circuit lines. Some companies have recently developed screen-printing techniques which can provide higher degrees of resolution. For example, General Electric has developed a method for screen-printing down to 0.01 inch resolution which can be used to manufacture printed circuit boards for appliances (Greene 1985). The majority of printed circuit board manufacturers, however, are still using the photolithographic technique for printed circuit boards having circuitry finer than 12 mil lines and spaces.

Use Asher dry photoresist removal method to eliminate the use of organic resist stripping solutions. Although this method is increasingly popular in the semiconductor industry, its use has not been reported by printed circuit board manufacturers, probably because the printed circuit board resists are usually much thicker than the corresponding semiconductor resist layers.

Recycle/reuse photoresist stripper. Photoresist stripper is used to remove photoresist material from the board. This photoresist is a polymer material that remains in the stripper tank in small flakes that slowly settle to the bottom. When the sludge formed at the bottom of the stripper tank builds up, the flakes begin to adhere to circuit boards and the stripper solution is considered spent. Increased use of the solution can be achieved by decanting and filtering the stripper solution out of the tank into a clean tank. This is feasible because the stripper usually becomes spent as a result of the residue buildup long before it becomes spent as a result of a decrease in chemical strength.

Electroplating and Electroless Plating

Source reduction methods associated with electroplating and electroless plating center around eliminating the need for the operation, reducing the hazardous nature of the materials used, extending process bath life, improving rinse efficiency, and recovering/reusing spent materials.

ELIMINATE NEED FOR OPERATION

Use mechanical board production methods/systems. For facilities that produce low-volume prototype circuit boards, mechanical board production systems are available which bypass all operations involving chemicals. Circuit boards are designed on a computer and the pattern is then etched by means of a mechanical stylus on a copper-clad board. While this system is not viable for producing boards in large quantities, it is highly suited for use in development/research settings.

REDUCE HAZARDOUS MATERIALS USED

Use non-cyanide plating baths.

Use non-cyanide stress relievers. In the case of electroless copper plating, water soluble cyanide compounds of many metals are typically added to eliminate or minimize the internal stress of the deposit. It has been found that polysiloxanes are also effective stress relievers (Durney 1984). By substituting polysiloxanes for cyanides, the hazardous nature of the spent bath solution can be reduced.

EXTEND PROCESS BATH LIFE

Process baths may contain high concentrations of heavy metals, cyanides, solvents and other toxic constituents. They are not discarded frequently but rather are used for long periods of time. Nevertheless, they do require periodic replacement due to impurity build-up resulting from drag-in or decomposition and the loss of solution constituents by drag-out. When a solution is contaminated or exhausted, the resulting waste solution may contain high concentrations of toxic compounds and require extensive treatment. The source control methods available for extending process bath life include reducing or removing impurities formed in the bath, reducing the loss of solution (drag-out) from the bath, and maintaining bath solution quality.

Reduce Impurities

Impurities come from five sources: racks, anodes, drag-in, water or chemical make-up, and air. The buildup of impurities can be limited by the following techniques:

Proper rack design and maintenance. Corrosion and salt buildup deposits on the rack elements contaminate solutions if they chip away or fall into the solution. Proper design and regular cleaning will minimize this form of contamination. Fluorocarbon coatings applied to the racks have also been found to be effective (Lane 1985). Such a coating lowers drag-out as well since less bath solution remains in the corroded crevices on the racks or barrels.

Use purer anodes and anode bags. During the plating process, metal from the anode dissolves in the plating solution and deposits on the cathode (workpiece). Some of the impurities contained in the original anode matrix stay behind in the plating solution, eventually accumulating to prohibitive levels. Thus, the use of purer metal for the anode extends the plating solution life. Anode bags can also be used to prevent pieces of decomposed anodes from falling into the tank.

Drag-in reduction by better rinsing. Efficient rinsing of the workpiece between different process baths reduces the drag-in of plating solution into the next process bath.

Use of deionized or distilled make-up water. To compensate for evaporation, water is required for makeup of plating solutions. Using deionized or distilled water is preferred over tap water, since tap water may have a high mineral or solids content, which can lead to impurity buildup.

Proper storage of chemicals. Proper storage of the process solutions can also reduce waste generation. Usually, the process solutions are stored as a two-part solution and are mixed when a batch is needed. Prolonged storage of mixed solutions may allow some chemical reactions to occur that could generate contaminants that reduce bath life. In electroless copper plating, if formaldehyde (a reducing agent) is stored with a hydroxide, the hydroxide can cause the formaldehyde to break down into formic acid and methyl alcohol. Thus, it is better to only store non-reactive mixtures of materials or to store each item separately.

Once you have reduced impurity buildup in the bath, you need to concentrate on reducing solution losses through drag out.

Reduce Drag-Out

Several factors contribute to drag-out. These include workpiece size and shape, viscosity and chemical concentration, surface tension, and temperature (USEPA, 1982a). By reducing the volume of drag-out that enters the rinse water system, valuable process chemicals can be saved and sludge generation can be reduced. More discussion of the impact on sludge generation due to drag-out is presented under "alternative treatment methods."

During the course of this study, it was found that most printed circuit board manufacturers have little idea of the volume of drag-out their various process lines generate. Process chemical suppliers assess drag-out using a standard rate of 10 to 15 ml/ft2 of circuit board (Foggia 1987). However, this standard rate does not take into account the various process bath operating parameters that can be used or the effects of various workpiece rack withdrawal methods. Nevertheless, this standard drag-out rate is a good starting point for determining the impact of drag-out on waste generation. Factors affecting drag-out are described in Table 3.

Table 3. Factors That Increase the Amount of Drag-Out

High surface tension
Highly viscous plating solution
Larger workpiece size
Faster workpiece withdrawal
Shorter drainage time
Orientation of workpiece during removal so that drainage is reduced

Generally, drag-out minimization techniques include:

Minimize bath chemical concentration. Controlling the chemical concentration of the process bath can reduce drag-out losses in two ways. Reducing toxic chemical concentrations in a process solution reduces the quantity of chemicals and the toxicity in any dragout that occurs. Also, greater concentrations of some of the chemicals in a solution increase the viscosity (USEPA 1982a). As a result, the film that adheres to the workpiece as it is removed from the process bath is thicker and will not drain back into the process bath as quickly. Therefore the volume of drag-out loss is increased and a higher chemical concentration in the drag-out is created. In electroless copper plating for printed circuit board manufacture, dilute solutions have been tried successfully by many manufacturers (USEPA 1981).

Chemical product manufacturers may recommend an operating concentration that is higher than necessary to perform the job. A printed circuit board manufacturer should determine the lowest process bath concentration that will provide adequate product quality. This can be done by mixing a new process bath at a slightly lower concentration than normal. As fresh process baths are mixed the chemical concentration can continue to be reduced until product quality begins to be affected. At this point, the manufacturer can identify the process bath that provides adequate product quality at the lowest possible chemical concentration.

Fresh process baths can often be operated at lower concentrations than used baths. Makeup chemicals can be added to the used bath to gradually increase the concentration. This procedure allows newer baths to be operated at lower concentrations and older baths to be maintained for longer periods of time before requiring disposal.

Increase bath operating temperature in order to lower viscosity. Increased temperature lowers both the viscosity and surface tension of the solution, thus reducing drag-out. The resulting higher evaporation rate may also inhibit the carbon dioxide absorption rate, slowing down the carbonate formation in cyanide solutions. Unfortunately, this benefit may be lost due to the formation of carbonate by the breakdown of cyanide at elevated temperatures. Additional disadvantages of this option would include higher energy costs, higher chance for contamination due to increased make up requirement, and increased need for air pollution control due to the higher evaporation rate.

Use wetting agents. Wetting agents can be added to a process bath to reduce the surface tension of a solution and, as a result, reduce the volume of drag-out loss. The use of wetting agents in the metal finishing industry has been estimated to reduce drag-out loss by as much as 50 percent (USEPA, 1982a). However, most printed circuit board manufacturers prefer using process chemicals that are free of wetting agents because they can create foaming problems in the process baths. Although the process bath chemistries of a printed circuit board manufacturing line may not always allow the addition of wetting agents, their use should be evaluated.

Position workpiece properly on the plating rack. When a workpiece is lifted out of a plating solution on a rack, some of the excess solution on its surface (drag-out) will drop back into the bath. Proper positioning of the workpiece on a rack will facilitate maximum drainage of drag-out back into the bath. The position of any object which will minimize the carry-over of drag-out is best determined experimentally, although the following guidelines were found to be effective (USEPA 1981):

- Orient the surface as close to vertical as possible.
- Rack with the longer dimension of the workpiece horizontal.
- Rack with the lower edge tilted from the horizontal so that the runoff is from a corner rather than an entire edge.

While positioning of the printed circuit board offers little variability -- the boards are generally placed upright in a rack -- a board that is tilted at an angle, allowing it to drip down onto an adjacent board instead of directly into the bath, may lead to increased drag-out loss. The operator must ensure that the workpiece is positioned properly to prevent unnecessary drag-out loss.

Withdraw boards slowly and allow ample drainage. The faster an item is removed from the process bath, the thicker the film on the workpiece surface and the greater the drag-out volume will be. The effect is so significant that it is believed that most of the time allowed for withdrawal and drainage of a rack should be used for withdrawal only (USEPA, 1982a). However, since workpieces are usually removed from a process bath manually, it is difficult to control the speed at which they are withdrawn. Nevertheless, supervisors and management should emphasize to process line operators that workpieces should be withdrawn slowly.

Workpiece drainage once the part is removed from the bath also depends on the operator. The time allowed for drainage can be inadequate if the operator is rushed to remove the workpiece rack from the process bath area and place it in the rinse tank. However, installation of a bar or rail above the process tank, and the requirement that all workpieces be hung from it for at least 10 seconds, may help ensure that

adequate drainage time is provided prior to rinsing. Printed circuit board manufacturers express concern that increasing workpiece rack removal and drainage time will allow for chemical oxidation on the board. Although some process steps may not be amenable to these drag-out reduction techniques, increased workpiece rack removal and drainage time can still be effective for many process steps.

Use computerized/automated control systems. Computerized process-control systems can be used for board handling and process bath monitoring to prevent unexpected decomposition of the plating bath. Since the use of a computerized control system not only requires a large capital outlay for initial installation but also increases the demand for skilled operations and maintenance personnel, only very large companies which manufacture both printed circuit boards and other electronic components are incorporating this change in their manufacturing process. For example, Hewlett-Packard in Sunnyvale, California reported its successful use of computers for plating operations on printed circuit boards (Anonymous 1983).

Recover drag-out from baths. In addition to reducing the volume of drag-out that is lost from the process bath, printed circuit board manufacturers can recover drag-out losses by using drain boards and close-circuit rinsing. Drain boards are used to capture process chemicals that drip from the workpiece rack as it is moved from the process bath to the rinse system. The board is mounted at an angle that allows the chemical solution to drain back into the process bath. Drainage boards should be installed if there is space between the process bath tank and the rinse tank where chemical solutions would otherwise drip onto the floor and enter the wastewater system when the floor is washed down.

Another method of reducing drag-out loss is to recover it for reuse in the process tank. The most common way to do this is through use of drag-out tanks (also called still or dead rinses). Drag-out tanks can be used to capture process chemicals that adhere to the circuit board and return them to the process bath. Drag-out tanks are essentially rinse tanks that operate without a continuous flow of feed water. Chemical concentrations in these tanks increase as more workpieces are passed through. Since there is no feed water flow to cause rinse water turbulence, air agitation is often used to enhance rinsing. After a period of time, the concentration of the drag-out tank solution will increase to the point where it can be used to replenish the process bath. Drag-out tanks are primarily used with process baths that operate at an elevated temperature. The high temperature causes evaporative water losses that can be compensated for by adding the drag-out tank solution back to the process bath. If the evaporation rate of the process tank is not high enough, evaporators can be installed on it. They can also be installed on the drag-out tank, to further concentrate the rinse solution to be used as makeup.

Closed-circuit rinse systems can employ continuously flowing rinses as well as static rinses that are periodically added as makeup to the process bath. Often, two or more rinses are used in a counter-current arrangement such as is illustrated in Figure 2. In this arrangement, the work is first rinsed in the least clean rinse bath, and then in successively cleaner baths. Spent rinse water from the cleanest bath gets added to the next cleanest bath, and eventually to the process bath itself. The use of closed-circuit rinses can be very significant in reducing the amount of heavy metal wastes and other hazardous chemicals in the waste streams (Meltzer 1989).

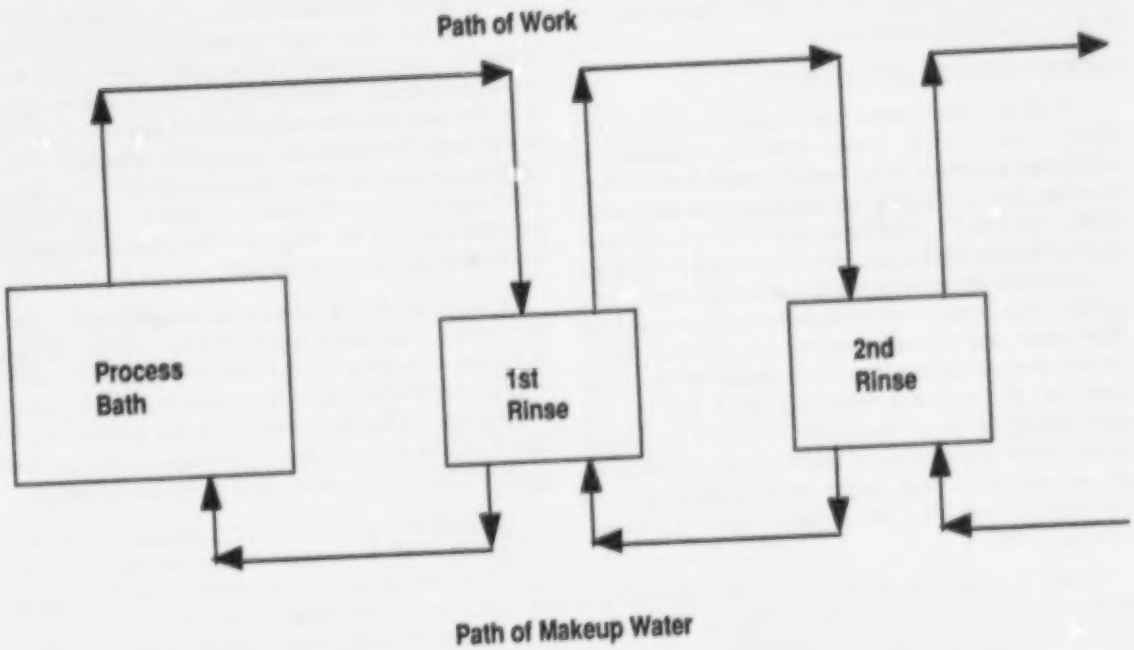
The printed circuit board manufacturing companies visited during this study all used drag-out tanks, but none of them used the drag-out solution to replenish the process bath. Instead, these companies dumped the solutions into their treatment systems. They are reluctant to reuse the drag-out solution because of fear of contamination. Since a drag-out tank can often be used for more than a week between dumps and because the tank is uncovered, operators are concerned that someone could improperly use the tank to rinse a workpiece; the contaminated drag-out solution would then contaminate the process bath when used to replenish the process tank. Also, some process bath chemistries are such that adding drag-out solution back into the process tank would spoil the bath. For example, electroless copper baths contain chemicals that break down in a diluted drag-out solution. If the solution is then added back to the process tank, these breakdown chemicals could adversely affect the electroless copper bath (Stone 1987). If the potential for contamination or deterioration of the drag-out solution can be overcome, however, drag-out tanks can be used on copper and tin/lead electroplating lines.

Maintain Bath Solution Quality

Once the amount of drag-in and drag-out from the process bath has been reduced, attention should focus on ways to maintain the bath at optimum operating conditions. Many facilities rely on drag-out from the bath as the way of purging impurities that would otherwise build up and interfere with operation. From an environmental viewpoint, this is a poor technique since it does not directly address the issue of impurity formation, results in high losses of valuable process solutions, and moves the problem downstream to the treatment unit.

The following methods are noted as ways of increasing bath life and minimizing the impact on existing treatment systems:

Figure 2. Multiple Closed Circuit Counterflow Rinse System



Monitor solution activity. By frequent monitoring of the bath activity and regular replenishment of reagents or stabilizers, bath life can be prolonged (Durney 1984). These reagents or stabilizers differ from process to process. Stabilizers such as 2-mercaptobenzothiozole and methanol are found effective in electroless copper plating used for manufacturing printed circuit boards. The addition of stabilizers can sometimes decrease the deposition rate, but can still be economical in the long run.

Control bath temperature. Good control of the bath temperature is important from the viewpoint of performance predictability and is another method of prolonging bath life. Many surface treatment operations use tanks with immersed cooling/heating coils. As the salts precipitate and form scales on the coils the heat transfer is impeded and temperature control becomes increasingly difficult. Heat transfer efficiency can be maintained by periodic cleaning of the coils or by using jacketed tanks instead of coils.

Use mechanical agitation. Many process baths employ air agitation to increase and maintain the efficiency of the bath. This practice can introduce contaminants into the bath. The two principal contaminants are oil from the compressor or blower and carbon dioxide. The oil will lead to undue organic loading while the carbon dioxide can lead to carbonate buildup in alkaline baths. A viable alternative is to use mechanical agitation.

Use continuous filtering/carbon treatment. To avoid surface roughness in the plating resulting in high reject rates, baths should be continuously filtered to remove impurities. The flow rate to the filter should be as high as practical to prevent particles from settling on the parts. Since filters can seldom remove solids at the same rate that they are introduced by way of drag-in, filtering should be performed even when the bath is not in use. Install as coarse a filter as practical, since coarse filters allow higher loading before requiring replacement, allow for higher flow rates and hence greater tank turn-overs, and require less servicing. When organic buildup is a problem, use of carbon filter cartridges is appropriate.

Regenerate solution through impurity removal. There are methods that have been successfully used to increase the longevity of plating solutions through impurity removal.

More efficient filtering of a plating solution has kept levels of impurities low and extended solution life (McRae 1985). Metallic salts can sometimes be removed by temporarily lowering the bath temperature so as to form solid crystals. In the case of electroless nickel plating, the sodium sulfate that forms can be crystallized by lowering the bath temperature to 41-50oF (Durney 1984). The crystals can then be removed by filtration.

IMPROVE RINSE EFFICIENCY

Most hazardous waste from a printed circuit board manufacturing plant comes from the treatment of wastewater generated by the rinsing operations that follow cleaning, plating, stripping, and etching processes (Couture 1984). Three basic strategies are used to provide adequate rinsing between various process bath operations. These are (1) turbulence between the workpiece and the rinse water, (2) sufficient contact time between the workpiece and the rinse water, and (3) sufficient volume of water during contact time to reduce the concentration of chemicals rinsed off the workpiece surface (USEPA 1982a). The third strategy is most commonly employed by printed circuit board manufacturers. Reliance on this strategy causes printed circuit board manufacturers to use significantly more rinse water than is actually required (Couture 1984).

Many techniques are available that can improve the efficiency of a rinsing system and reduce the volume of rinse water used. These techniques include:

Use of closed-circuit rinses. As mentioned above, installing one or more closed-circuit still or counter-flow rinsing tanks immediately after a plating bath allows for metal recovery and lowered rinse water requirements. The contents of the rinses are used to replenish the upstream plating bath. As previously mentioned, a major problem with the use of still rinses is that while they are commonly installed at many plants, operators typically do not return the solution to the bath due to concern over solution contamination.

Generally, the use of a drag-out or still rinse tank can reduce both rinse water usage and chemical losses by 50 percent or more (USEPA 1982a). Assuming that a chemical bath processes 3,000 square feet of board each month, the total volume of process bath drag-out loss each month would be 12 gallons, with a drag-out rate of 15 ml/square foot of board. If the rinse system following the process bath operates at a flow rate of 10 gpm for a total of two hours each day, water usage would be 24,000 gallons per month based on 20 work days per month. A 50 percent reduction in process bath chemical loss and water usage achieved by installing a drag-out tank would reduce process bath losses by six gallons per month and water usage by 12,000 gallons.

Use spray rinsing. Although spray rinsing uses between one-eighth and one-fourth the volume of water that a dip rinse uses (USEPA 1982a), it is not always applicable to printed circuit board manufacturing because the spray rinse may not reach many parts of the circuit board. However, spray rinsing can be performed along with immersion rinsing. This technique uses a spray rinse as the first rinse step after the workpieces are removed from the process tank. The spray rinsing typically takes place while the parts are draining above the process tank. This permits lower water flows in the rinse tank because spray rinsing removes much of the drag-out before the workpiece is submerged into the dip rinse tank.

Use fog nozzles. A variation on the spray nozzle is the fog nozzle. A fog nozzle employs water and air pressure to produce a fine mist. Much less water is needed than with a conventional spray nozzle. It is more often possible to use a fog nozzle rather than a spray nozzle directly over a heated plating bath to rinse the workpiece, because less water is added to the process bath using the fog nozzle.

Increase degree of agitation. Agitation between the workpiece and the rinse water can be performed either by moving the workpiece rack in the water or by creating turbulence in the rinse water. Since most printed circuit board manufacturing plants operate hand rack lines, operators could easily move workpieces manually by agitating the hand rack. However, the effectiveness of this system depends on cooperation from the operator.

Agitating the rinse tank by using forced air or water is the most efficient method for creating effective turbulence during rinse operations. This is achieved by pumping either air or water into the immersion rinse tank rinsing operations. Air agitation provides the best rinsing because the air bubbles create the best turbulence for removing the chemical process solution from the workpiece surface (USEPA 1982a). This type of agitation can be performed by pumping filtered air into the bottom of the tank through a pipe distributor (air sparger). Great care should be exercised, however, to ensure that the air is free of dust or oil so as not to contaminate the boards being cleaned. Assuming the plant has a sufficient quantity of compressed air onsite that is readily available, the cost of installing air spargers is $100 to $125 per tank for a 50 gallon capacity tank.

Use counter current rinse stages. Multiple stage rinse tanks increase contact time between the workpiece and the rinse solution and thereby improve rinsing efficiency compared to a single-stage rinse. If these multiple tanks are set up in series as a counter current rinse system, water

usage can also be reduced. Manufacturers do not need to rely on large volumes of rinse water to prevent chemical concentrations in the rinse solution from becoming excessive. Multiple rinse tanks can be used to provide sufficient rinsing while significantly reducing the volume of rinse water used. A multistage counter current rinsing system can use up to 90 percent less rinse water than a conventional single-stage rinse system (Couture 1984).

The effectiveness of a multistage system in reducing rinse water usage is illustrated in the following example. A plant operates a process line where approximately 1.0 gallon of drag-out per hour results from a chemical process bath. This process bath is followed by a single-stage rinse tank. The process requires a dilution rate of 1000 to 1 to maintain acceptable rinsing in the tank. Therefore, the flow rate through the rinse tank is 1000 gal/hr. If a double stage counter current rinse system were used, a rinse water flow rate of only 30 to 35 gal/hr would be needed. If a triple stage counter current rinse system were used, only 8 to 12 gal/hr would be required (Watson 1973).

A multistage counter current rinse system allows greater contact time between the workpiece and the rinse water, greater diffusion of process chemicals into the rinse solution, and more rinse water to come into contact with the workpiece. The disadvantage of multistage counter current rinsing is that more process steps are required and additional equipment and work space are needed. A counter current triple-rinse system requires the installation of two additional rinse tanks and the associated piping. The cost of such a system is typically about $1,000 (Terran 1987).

Proper equipment design/operation. Printed circuit board manufacturers can use excessive amounts of rinse water if their water pipes are oversized or if the water is left on even when the rinse tanks are not being used. Rinse water control devices can be installed to increase the efficiency of a rinse water system. Flow restrictors limit the volume of rinse water flowing through a rinse system. These are used to maintain a constant flow of fresh water into the system once the optimal flow rate has been determined. Also, since most small and medium-sized printed circuit board manufacturers operate batch process lines in which rinse systems are manually turned on and off throughout the day, pressure activated flow control devices, such as foot pedal activated valves, can be helpful for assuring that the water is not left on after the rinse operation is completed. If the water lines are over-sized at a plant, pressure-reducing valves can be installed upgradient of the rinse water influent lines. This is also helpful for controlling water use in the rinse tanks.

A conductivity probe or pH meter can also be employed to control fresh water flow through a rinse system. A conductivity/pH cell is used to measure the level of dissolved solids or hydrogen ions in the rinse solution. When this level reaches a pre-set minimum, the conductivity probe activates a valve that shuts off the flow of fresh water into the rinse system. When the concentration builds to the pre-set maximum level, the probe again activates the valve, which then opens to continue the flow of fresh water. This control equipment is especially valuable to the printed circuit board manufacturing industry. A pH meter equipped with the necessary control valves and solenoids could cost approximately $700 per tank (Ryan 1987).

Use deionized water for rinsing. Natural contaminants found in water used for production processes can contribute to the volume of waste generated. During treatment of wastewater, these natural contaminants precipitate as carbonates and phosphates and contribute to the volume of sludge (USEPA 1982b). The extent to which these contaminants increase sludge volume depends on the hardness of the rinse water. In addition to the direct effect on sludge volume, the presence of natural contaminants in the water may reduce rinse water efficiency and the ability to reuse/recycle rinse water. Therefore, rinse systems may require more water than would be necessary if the water were pretreated.

The cost of deionizing process water depends on the condition of the water supplied to the plant. The cost is dependent on the concentration of total dissolved solids (TDS) in the water (Prothro 1987). For example, in the Santa Clara Valley a plant supplied with surface water spends approximately 2 cents per gallon to pretreat process water. A plant supplied with ground water spends close to 4 cents per gallon. A typical deionizing system that includes two 14-inch mixed bed deionizers costs approximately $2,000 for equipment and installation and treats up to 5,000 gallons a day (Prothro 1987).

RECOVERY/REUSE OF SPENT MATERIALS

Recycling and resource recovery includes technologies that use waste as raw material for another process or that recover valuable materials from a waste stream before the waste is disposed of. Opportunities for both the direct use of waste materials and the recovery of materials from a waste stream are available to the printed circuit board manufacturing industry. Many of the spent chemical process baths and much of the rinse water can be reused for other plant processes. Also, process chemicals can be recovered from rinse waters, and valuable metals such as copper can be recovered from waste streams.

A printed circuit board manufacturer must understand the chemical properties of its waste stream before it can assess the potential for reusing the waste raw material. Although the chemical properties of a process bath or rinse

water solution may become unacceptable for their original use, these waste materials can still be employed in other applications. Printed circuit board manufacturers should therefore evaluate waste streams for properties that make them useful as well as properties that render them waste.

Segregate Streams to Promote Recycling

In a typical facility, the mixing of different rinse streams is not uncommon, and in the recent past, rinse waters and spent baths were frequently mixed and treated together. By segregating various rinses, their reuse or recycling can be promoted. Metal reclamation by electrolysis from various streams is made easier if they are not mixed.

Recover Metal Values from Bath Rinses

In the past, copper and other metal recovery from printed circuit board manufacturing has not proven to be economical. However, effluent pretreatment regulations have made the cost of treatment an economic factor. Also, the cost of management of sludges containing heavy metals has increased significantly because of the increased regulatory requirements placed on the handling and disposal of hazardous wastes. As a result, board manufacturers may now find it economical to recover copper and other metals and metal salts lost due to drag-out from process chemical baths.

Recovered metal can be used in two ways: (1) recovered metal salts can be recirculated back into process baths, and (2) recovered elemental metal can be sold to a metals reclaimer. Some of the technologies that are being successfully used to recover metals and metal salts include:

Evaporation. Waste rinse water is evaporated by heating, leaving behind a concentrated solution. The equipment used includes single or multiple effect evaporators. Vapor recompression applications have also been reported (Seaburg and Bacchetti 1982). In evaporative methods, the solution is concentrated until its metal concentration is equal to that of the plating bath, and then this solution is reused. Using this method, 90-99 percent efficient metal recoveries can be achieved (Clark 1984). Depending on the design, the evaporated water vapor can either be condensed and re-used as rinse water, or it can be vented off into the atmosphere (Campbell and Glenn 1982). Evaporation is the best established of all the metal recovery techniques used in electroplating. Although it is the most energy intensive recovery technique, its simplicity and reliability make it an attractive option for metal recovery. In order for evaporation to be economical, multiple counter current rinse tanks or spray/fog rinsing should be used to minimize the amount of rinse water being processed (MDEM 1984). Apart from the energy cost, a distinct disadvantage of evaporative techniques is that the concentrates may also contain the calcium and magnesium salts originally present in the rinse water. Adding them to the plating solution may result in its more rapid deterioration. This problem is alleviated in situations where rinse water is de-ionized or softened prior to use.

Reverse osmosis. Reverse osmosis is also used to recover drag-out that can be returned to the process bath. The reverse osmosis process employs a semipermeable membrane that permits only certain components to pass through. When pressure is applied, these components pass through the membrane and concentrate in the recovered solution. Although the technology is designed to recover drag-out, some materials (such as boric acid) can not be fully recovered and are, therefore, returned to the process bath at a lower concentration. Also, reverse osmosis is a delicate process that is limited by the ability of the membranes to withstand pH extremes and long-term pressure. Reverse osmosis systems are commonly used to recover nickel plating solutions and regenerate rinse waters.

Liquid membranes. Liquid membranes are composed of polymeric materials loaded with an ion-carrying solution (Basta 1983). Liquid membranes have been used to remove chromium from rinse waters and spent etching baths. Chromium in the form of dichromate is drawn across the membrane, forming a tertiary amine metal complex. This complex is then broken down on the other side of the membrane with sodium hydroxide solution.

Ion exchange. Ion exchange concentrates metals from a dilute rinse stream onto a resin material. As rinse water is passed through a bed containing the resin, the resin substitutes ions for inorganics in the rinse water. The metals are then recovered from the resin by cleaning it with an acid or alkaline solution. Ion exchange units can be used effectively on dilute waste streams and are less delicate than reverse osmosis systems. However, the equipment is complex and requires careful operating and maintenance practices.

Electrolytic recovery. This method recovers only the metallic content of rinse water. The process requires a cathode and an anode placed in the rinse solution. As current passes from the anode to the cathode, metallic ions deposit on the cathode. This type of system generates a solid metallic slab that can be reclaimed or used as an anode in an electroplating tank. Electrolytic systems can recover 90 to 95 percent of the available metals. Electrolytic recovery has been successfully used to recover gold, silver, tin, copper, zinc, solder alloy, and cadmium (Campbell and Glenn 1982). One great advantage of the electrolytic method over other metal recovery techniques is that it recovers only the plating metal, not the impurities, from the waste rinse water. Electrolytic metal recovery is most

efficient on concentrated solutions. For solutions with less than 100 mg/l of the metal ion, low current efficiencies limit process effectiveness.

Electrodialysis. In electrodialysis, an electric current and selective membranes are used to separate the positive and negative ions from a solution into two streams. This is accomplished by feeding a solution through a series of alternating cation and anion selective membranes, through which a current is passed. Electrodialysis is used mainly to concentrate dilute solutions of salts or metal ions. Electrodialysis can remove nickel, copper, cyanide, chromium, iron and zinc from waste rinse water (MDEM 1984, Kohl and Triplett 1984). This technology has not been used as widely in the electroplating industry as have other metal recovery techniques (Campbell and Glenn 1982, Kohl and Triplett 1984).

High surface area electrowinning/electrorefining. This method operates on the same principle as electrolytic recovery. The metal-containing solution is pumped through, and plates out on, a carbon fiber cathode (Mitchell 1984). To recover the metals, the carbon fiber cathode assembly is removed and placed in an electrorefiner, which reverses the current, removes the metals from the carbon fibers, and allows them to plate onto a stainless steel starter sheet. These systems can be used to recover a wide variety of metals and to regenerate many types of solutions.

The cost associated with implementing a chemical recovery technology depends on a number of variables: the size of the unit, the space available, equipment rearrangement, production down time, and the specific application. Table 4 contains cost data for several chemical recovery units from electroplating plants. Although the specific materials recovered may be different for a printed circuit board manufacturing plant, the basic technology is transferable between these two industries. While the equipment costs shown can be applied to board manufacturing, the annual savings depend on the wastewater metal concentrations and volume of wastewater treated by the recovery systems.

One limiting factor for a small printed circuit board manufacturing company is the volume and chemical concentration of its various rinse water effluents. The examples in Table 4 are all designed to recover a specific material from a single waste generating source (for example, nickel salts from a nickel plating line). To achieve savings in chemicals and sludge handling that create a justifiable payback, the waste stream must be fairly concentrated and continuous. Each company must evaluate its own conditions to determine the feasibility of material recovery. The information necessary to determine the feasibility includes waste stream generation rates and chemical concentrations, and the value of materials to be recovered.

Etching

Most of the source control techniques listed under plating and electroplating apply as well to waste produced by etching. Special source reduction methods associated with etching operations are discussed below.

Use differential plating instead of the conventional electroless plating process. If the concentrations of certain stabilizers in the electroless copper bath are controlled, copper deposits three to five times faster on the through-hole walls than on the copper cladded surface (Poskanzer and Davis 1982). This reduces the amount of copper that must be subsequently etched away in the subtractive method. The use of differential electroless plating has not been reported by printed circuit board manufacturers, and it may require significant developmental work before commercialization is possible.

Use non-chelated etchants. Non-chelate mild etchants such as sodium persulfate and hydrogen peroxide/sulfuric acid can be used to replace ammonium persulfate chelate etchant.

Use thinner copper foil to clad the laminated board. This change reduces the amount of copper which must be etched, and thus reduces the amount of waste generated from the etching process. Printed circuit board manufacturers are switching to boards cladded with thinner copper as their starting materials.

Use pattern instead of panel plating. Since panel plating consists of copper plating the entire board area, while pattern plating requires copper electroplating only the holes and circuitry, the use of the latter technique reduces the amount of non-circuit copper which must be subsequently etched away. This practice can therefore reduce the amount of waste generated from the etching operation. The switch from panel to pattern plating has been made by a large number of printed circuit board manufacturers. Customers demanding applications for a uniform cross section of circuitry in computer and microwave printed circuit boards, however, may dictate the use of panel plating to provide highly uniform copper thickness.

Use additive instead of subtractive method. This change eliminates the copper etching step, and therefore eliminates the generation of substantial volumes of spent etchant as well as reducing the amount of metal hydroxide sludges generated. Although the subtractive method is still the most widely used in the manufacturing of printed circuit boards, the additive method is gaining in popularity since it results in less waste and lower manufacturing costs (Brush 1983). A noted drawback to the additive method, however, is the requirement for solvent processable instead

Table 4. Costs of Technology for Material Recovery

Technology	Materials Recovered	Equipment Costs*
Evaporation Unit: Capacity of approximately 20 gph.	Rinse water Chromic acid	$47,000
Reverse Osmosis Unit: Capacity of approximately 100 gph.	Nickel salt Plating chemicals	$27,000
Ion Exchange Unit: Capacity of approximately 20 gph.	Rinse water Chromic acid	$38,000
Electrolytic Unit: Capacity of approximately 15 gph.	Rinse water Copper	$25,000

* Equipment costs include equipment purchase, installation, and materials.
Source: USEPA 1987.

of aqueous processable photoresists. Furthermore, the spent additive plating bath often contains heavily complexed copper which may result in waste treatment problems.

Use non-chrome etchants. Whenever possible, ferric chloride or ammonium persulfate solution should be used instead of chromic-sulfuric acid etchants. Non-chromium etching solution has reportedly been used by printed circuit board manufacturers in an effort to reduce the toxicity of the waste generated.

Recycle spent etchants. Use of an electrolytic diaphragm cell for regenerating spent chromic acid from etching operations has been reported (AESI 1981). The electrolytic cell oxidizes trivalent chromium to hexavalent chromium and removes contaminants. The quality of the regenerated etchant has been reported to be equal to or better than fresh etchant.

In one such application, extensively tested at the U.S. Bureau of Mines in Rolla, Mo., copper etching solution was regenerated and metallic copper recovered at the same time. Recovery was accomplished by depositing the copper onto the cathode of the electrolytic diaphragm cell (Basta 1983).

Another recycling example involves the regeneration of cupric chloride, used as a strong etchant for producing circuit patterns on circuit board base material. The etchant becomes spent as the copper etched from the base material reduces the cupric chloride (CuCl2) to cuprous chloride (CuCl). This spent etchant can be regenerated by oxidizing to cuprous chloride through direct chlorination (Couture 1984).

Wastewater Treatment

Process chemical loss due to drag-out is the most significant source of chemicals entering wastewater. Treatment of this wastewater is a major source of hazardous waste in PC board operation because of the resulting sludge. The volume of sludge generated is proportional to the level of contamination in the spent rinse water (Couture 1984). The major ways of reducing waste associated with treatment (in addition to those associated with drag-out reduction, reduction in the use of rinse water, and use of deionized water) include waste stream segregation, use of alternative treatment chemicals, and alternative treatment technologies.

WASTE STREAM SEGREGATION

Segregating waste streams can improve the efficiency of a waste treatment system. An example of waste stream segregation is the separation of chelating agent waste streams from nonchelating agent streams. Since most small printed circuit board manufacturing plants use treatment systems that can be operated as a batch process, they can implement waste stream segregation and selective treatment with minimal impact on the production system. The main drawback to this alternative is usually the limited storage capacity for the segregated waste streams.

If waste streams containing chelating agents are treated in a batch process separately from other waste streams, the

use of ferrous sulfate to break down the chelators can be minimized. Since the iron in ferrous sulfate will precipitate out in the sludge, reduction in its use will also reduce the volume of sludge generated.

By isolating cyanide-containing waste streams from waste streams containing iron or complexing agents, the formation of cyanide complexes is avoided, and treatment made much easier (Dowd 1985). Segregation of wastewater streams containing different metals also allows for metals recovery or reuse. For example, by treating nickel-plating wastewater separately from other waste streams, a nickel hydroxide sludge is produced which can be reused to produce fresh nickel plating solutions.

Another waste alternative is to separate noncontact cooling water from industrial wastes. It is likely that this cooling water can bypass the treatment system and be discharged directly to the sewer because it does not come in contact with process chemicals. This practice can reduce wastewater volume and, as a result, reduce the amount of treatment chemicals used. Also, acidic or alkaline waste streams that do not contain metals can simply be neutralized prior to discharge; therefore, if they are segregated from other wastes that require metal removal, the volume of treatment chemicals can be reduced. This, in turn, will reduce the volume of sludge generated.

USE OF ALTERNATIVE WASTE TREATMENT CHEMICALS

The selection of chemicals used in the waste treatment process can affect the volume of sludge generated. This selection should, therefore, consider a chemical's effect on sludge generation rates. For example, lime and caustic soda are two common chemicals used for neutralization and precipitation. Although lime costs less per unit of neutralizing capacity, it can produce as much as ten times more dry weight of sludge than caustic soda (USEPA 1982b).

Alum and ferric chloride are commonly employed as coagulating agents to improve floc formation. When used, they convert to hydroxides and contribute to the volume of sludge. Polyelectrolyte conditioners can also be used as coagulants, but they are more expensive than inorganic coagulants. However, polyelectrolytes do not add to the quantity of sludge and may actually be less expensive overall when considering waste handling costs. One printed circuit board manufacturer visited during this study recently switched from alum to a polyelectrolyte coagulant in order to reduce sludge generation. Specific data on the volume of sludge reduction are not yet available from the company.

The selection of alternative treatment chemicals depends on specific waste characteristics and removal efficiency needs for a particular treatment facility. The potential use of various treatment chemicals should be discussed with chemical manufacturers' representatives and experimented with to determine their effectiveness.

ALTERNATIVE WASTEWATER TREATMENT - ION EXCHANGE

Ion exchange systems can be employed to treat the entire wastestream prior to discharge to the publicly-owned treatment works. When used for this purpose, the ion exchange units do not recover process chemicals for reuse because all sources of wastewater are mixed prior to treatment. The units can be used to recycle rinse water, however, by utilizing an activated carbon treatment system following ion exchange treatment. The costs for operating an ion exchange system depend on the volume and chemical concentrations of the wastewater.

One plant visited recently installed an ion exchange system to replace its conventional precipitation/clarification treatment system. The ion exchange unit is designed for a treatment capacity of 12 to 14 gallons per minute. The unit does not generate any sludge but does generate approximately two 55-gallon drums of spent ion exchange resin each month. The old treatment system generated approximately four to six 55-gallon drums of sludge per month.

The ion exchange system was purchased and installed for approximately $16,000 and required one week of production down time to install. The system costs $1,000 per month to operate, including material purchases and waste disposal, compared to $1,500 per month for the old system. The new system also requires less labor to maintain it. The payback on investment for the new system is estimated to be 3.3 years.

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SECTION 4
GUIDELINES FOR USING THE WASTE MINIMIZATION ASSESSMENT WORKSHEETS

Waste minimization assessments were conducted at several printed circuit board manufacturing plants in California. The assessments were used to develop the waste minimization questionnaire and worksheets that are provided in the following section.

A comprehensive waste minimization assessment includes a planning and organizational step, an assessment step that includes gathering background data and information, a feasibility study on specific waste minimization options, and an implementation phase.

Conducting Your Own Assessment

The worksheets provided in this section are intended to assist printed circuit board manufacturers in systematically evaluating waste generating processes and in identifying waste minimization opportunities. These worksheets include only the assessment phase of the procedure described in the Waste Minimization Opportunity Assessment Manual. For a full description of waste minimization assessment procedures, refer to the EPA Manual.

Table 5 lists the worksheets that are provided in this section.

Table 5. List of Waste Minimization Assessment Worksheets

Number	Title	Description
1.	Waste Sources	Typical wastes generated at printed circuit board manufacturing plants.
2A.	Waste Minimization: Material Handling	Questionnaire on general handling techniques for raw material handling.
2B.	Waste Minimization: Material Handling	Questionnaire on procedures used for bulk liquid handling.
2C.	Waste Minimization: Material Handling	Questionnaire on procedures used for handling drums, containers and packages.
3.	Option Generation: Material Handling	Waste minimization options for material handling operations.
4.	Waste Minimization: Material and Process Substitution	Questionnaire on material and process substitutions.
5.	Option Generation: Material and Process Substitution	Waste minimization options for material and process substitution.
6A.	Waste Minimization: Process Modification	Questionnaire extending process bath life by reducing drag-in and drag-out.
6B & 6C.	Waste Minimization: Process Modification	Questionnaire on: 1) extending bath life by avoiding decomposition and impurity removal; and 2) improving rinse efficiency.
7.	Option Generation: Process Modification	Process modification waste minimization options.
8.	Waste Minimization: Good Operating Practices	Questionnaire on use of good operating practices.
9.	Option Generation: Good Operating Practices	Waste minimization options for good operating practices.
10A.	Waste Minimization: Segregation, Reuse, Recovery and Treatment	Questionnaire on opportunities for segregation and reuse of wastes.
10B.	Waste Minimization: Segregation, Reuse, Recovery and Treatment	Questionnaire on opportunities for recovery and treatment of wastes.

Firm _____ Site _____ Date _____	Waste Minimization Assessment Proj. No. _____	Prepared By _____ Checked By _____ Sheet __ of __ Page __ of __

WORKSHEET 1

WASTE SOURCES

Waste Source: Material Handling	Significance at Plant		
	Low	Medium	High
Off-spec materials			
Obsolete raw materials			
Spills & leaks (liquids)			
Spills (powders)			
Empty container cleaning			
Container disposal (metal)			
Container disposal (paper)			
Pipeline/tank drainage			
Laboratory wastes			
Evaporative losses			
Contaminated wipes and gloves			
Other			
Waste Source: Process Operations			
Board Scrap			
Board Cleaners			
Catalysts			
Electroless Plating Baths			
Photoresist			
Developers			
Copper Plating Baths			
Tin/Lead Plate			
Stripping Solutions			
Etching Solutions			
Nickel/Gold Electroplate			
Reflow Oil			
Rinsing			
Equipment Cleaning			
Other			

Firm _____	Waste Minimization Assessment	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet __ of __ Page __ of __

WORKSHEET
2A

WASTE MINIMIZATION: Material Handling

A. GENERAL HANDLING TECHNIQUES

Does the plant accept samples from chemical suppliers?	☐ yes	☐ no
Do unused samples become waste?	☐ yes	☐ no
Are suppliers required to take back unused samples they provide?	☐ yes	☐ no
Are all raw materials tested for quality before being accepted from suppliers?	☐ yes	☐ no

Describe safeguards to prevent the use of materials that may generate off-spec product: _____

Is obsolete raw material returned to the supplier?	☐ yes	☐ no
Is inventory used in first-in first-out order?	☐ yes	☐ no
Is the inventory system computerized?	☐ yes	☐ no
Does the current inventory control system adequately prevent waste generation?	☐ yes	☐ no

What information does the system track? _____

Is there a formal personnel training program on raw material handling, spill prevention, proper storage techniques, and waste handling procedures?	☐ yes	☐ no
Does the program include information on the safe handling of the types of drums, containers and packages received?	☐ yes	☐ no

How often is training given and by whom? _____

Describe spill containment used in material storage area: _____

Firm _____	Waste Minimization Assessment	Prepared By _____
Site _____		Checked By _____
Date _____	Proj. No. _____	Sheet __ of __ Page __ of __

WORKSHEET
2B

WASTE MINIMIZATION: Material Handling

B. BULK LIQUIDS HANDLING

What safeguards are in place to prevent spills and avoid ground contamination during the filling of storage tanks?

High level shutdown/alarms ❑ Secondary containment ❑
Flow totalizers with cutoff ❑ Other ❑

Describe the system: _____

Are air emissions from solvent storage tanks controlled by means of:

Conservation vents	❑ yes	❑ no
Nitrogen blanketing	❑ yes	❑ no
Adsorber/Absorber/Condenser	❑ yes	❑ no
Other vapor loss control sytem	❑ yes	❑ no

Describe the system: _____

Are all storage tanks routinely monitored for leaks? ❑ yes ❑ no

Describe procedure and monitoring frequency for above-ground/vaulted tanks: _____

Underground tanks: _____

How are the liquids in these tanks dispensed to the users? (i.e., in small containers or hard piped.) _____

What measures are employed to prevent the spillage of liquids being dispensed? _____

When a spill of liquid occurs in the facility, what dry cleanup methods are employed (e.g., wet or dry)? Also discuss the way in which the resulting wastes are handled: _____

Would different cleaning methods allow for direct reuse or recycling of the waste? (explain): _____

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WASTE MINIMIZATION: Material Handling

C. DRUMS, CONTAINERS, AND PACKAGES

Are drums, packages, and containers inspected for damage before being accepted? ❑ yes ❑ no
Are employees trained in ways to safely handle the types of drums & packages received? ❑ yes ❑ no
Are they properly trained in handling of spilled raw materials? ❑ yes ❑ no
Are stored items protected from damage, contamination, or exposure to rain, snow, sun & heat? ❑ yes ❑ no

Describe handling procedures for damaged items: _____

Does the layout of the facility result in heavy traffic through the raw material storage area? ❑ yes ❑ no
(Heavy traffic increases the potential for contaminating raw materials with dirt or dust and for causing spilled materials to become dispersed throughout the facility.)
Can traffic through the storage area be reduced? ❑ yes ❑ no

To reduce the generation of empty bags & packages, dust from from dry material handling and liquid waste due to cleaning of empty raw material drums, has the facility attempted to:

- Purchase hazardous materials in preweighed containers to avoid the need for weighing? ❑ yes ❑ no
- Use reuseable/recyclable drums with liners instead of paper bags? ❑ yes ❑ no
- Use larger containers or bulk delivery systems that can be returned to supplier for cleaning? ❑ yes ❑ no

Discuss the results of these attempts: _____

Are all empty bags, packages, and containers that contained hazardous materials segregated from those that contained non-hazardous wastes? ❑ yes ❑ no
Are containers properly "cleaned" (per EPA methods)prior to disposal? ❑ yes ❑ no

Describe the method currently used to dispose of this waste: _____

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OPTION GENERATION: Material Handling

Meeting Format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. General Handling Techniques		
Quality Control Check		
Return Obsolete Material to Supplier		
Minimize Inventory		
Computerize Inventory		
Formal Training		
B. Bulk Liquids Handling		
High Level Shutdown/Alarm		
Flow Totalizers with Cutoff		
Secondary Containment		
Air Emission Control		
Leak Monitoring		
Spilled Material Reuse		
Cleanup Methods to Promote Recycling		
C. Drums, Containers, and Packages		
Raw Material Inspection		
Proper Storage/Handling		
Preweighed Containers		
Reusable Drums		
Bulk Delivery		
Waste Segregation		

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WASTE MINIMIZATION: Material and Process Substitution

To reduce the use of hazardous chemicals and the generation of hazardous wastes, has the facility attempted to use any of the following methods:

CLEANING AND SURFACE PREPARATION

Abrasives instead of solvents, acids, or alkalis?	☐ yes	☐ no
Non-chelated cleaning compounds?	☐ yes	☐ no

PATTERN PRINTING AND MASKING

Aqueous processable resist instead of solvent based resist?	☐ yes	☐ no
Screen printing instead of photolithography to eliminate need for developers?	☐ yes	☐ no
Dry photoresist removal methods to avoid use of organic strippers?	☐ yes	☐ no

ELECTROPLATING AND ELECTROLESS PLATING

Mechanical board production methods?	☐ yes	☐ no
Non-cyanide process baths?	☐ yes	☐ no
Non-cyanide stress relievers?	☐ yes	☐ no

ETCHING

Differential plating instead of conventional electroless plating?	☐ yes	☐ no
Pattern instead of panel plating?	☐ yes	☐ no
Additive instead of subtractive methods?	☐ yes	☐ no
Non-chelated etchants?	☐ yes	☐ no
Non-chromated etchants?	☐ yes	☐ no

WASTEWATER TREATMENT

Alternative (low dry solids volume) chemicals?	☐ yes	☐ no
Alternative treatment methods?	☐ yes	☐ no

Discuss the results of these attempts: _____

_____

_____

Discuss the obstacles that prevent the use of these methods: _____

_____

_____

Note: The auditor should refer to the USEPA report on Waste Minimization in Metal Parts Cleaning for information regarding material subetitution and process modification aimed at reducing waste from parts cleaning.

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OPTION GENERATION: Material and Processing Substitution

Meeting Format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Substitution Options		
Abrasives		
Non-chelated Cleaning Compounds		
Aqueous Processable Resist		
Screen Printing		
Dry Resist Removal		
Mechanical Production		
Non-cyanide Process Baths		
Non-cyanide Stress Relievers		
Differential Plating		
Use Thinner Copper Cladding		
Pattern Plating		
Additive Method		
Non-chelated Etchants		
Non-chrome Etchants		
Other Raw Material Substitution		

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6A

WASTE MINIMIZATION: Process Modification

For cleaning, electroplating, electroless plating, and etching, there are many similar ways of reducing waste. This is because most of these operations involve the insertion and removal of a part from a tank of processing solution followed by the rinsing of the part in a tank of water. Waste can be reduced by extending process bath life (reduce drag-in, reduce drag-out, avoid bath decomposition and remove impurities) and by improving rinse efficiency.

A. EXTENDING PROCESS BATH LIFE

Drag-In Reduction

Are racks cleaned regularly to ensure that corrosion does not contaminate the process baths?	☐ yes	☐ no
Are coated racks used to avoid contamination?	☐ yes	☐ no
Has the plant investigated the use of purer anodes to avoid contamination from metallic impurities in the anodes?	☐ yes	☐ no
Are anode bags used to prevent corroded anodes from falling into the bath?	☐ yes	☐ no
Are anodes removed when the bath is not in use?	☐ yes	☐ no
Is rinsing adequate to prevent or minimize drag-in?	☐ yes	☐ no
Is deionized water used for process bath make-up?	☐ yes	☐ no
Are chemicals properly stored and mixed just before use to avoid decomposition and shortened bath life?	☐ yes	☐ no

Drag-Out Reduction

Are process baths operated at the lower end of the manufacturer's suggested range of operating concentrations?	☐ yes	☐ no
Are fresh process bath solutions operated at a lower concentration than replenished process bath solutions?	☐ yes	☐ no
Can any of the chemical process baths be operated at a higher temperature without adversely affecting production quality?	☐ yes	☐ no
Has the plant investigated the use of wetting agents to reduce drag-out?	☐ yes	☐ no
Are boards properly racked to avoid excessive drag-out (typical drag-out values should range from 10 to 15 ml/ft²)?	☐ yes	☐ no
Are boards withdrawn slowly, and is ample time provided to allow for drainage?	☐ yes	☐ no
Has an optimal removal rate and drainage time for workpiece racks been determined for each process bath?	☐ yes	☐ no
Are personnel trained to follow proper workpiece rack removal rates & drainage times?	☐ yes	☐ no
Would use of an automatic board handler reduce drag-out?	☐ yes	☐ no
Is there space between process bath tanks and their associated rinse tanks that allows process chemicals to drip onto the floor?	☐ yes	☐ no
If yes, can drain boards be used to direct drainage back into the process tank?	☐ yes	☐ no
Do process baths that operate at elevated temperatures utilize drag-out tanks as the initial rinse following the bath?	☐ yes	☐ no
If yes, is the drag-out tank solution added back to the process tank?	☐ yes	☐ no
Has the company studied the possibility of using the drag-out solution for process bath replenishing?	☐ yes	☐ no

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6B

WASTE MINIMIZATION: Process Modification

Avoiding Bath Decomposition and Impurity Removal

Is bath activity regularly monitored?	❑ yes	❑ no
Are corrective actions taken promptly to promote maximum bath life?	❑ yes	❑ no
Is bath temperature properly controlled?	❑ yes	❑ no
Are heating coils cleaned regularly?	❑ yes	❑ no
Has the plant used heated jacketed tanks instead of coils?	❑ yes	❑ no
Are the process baths agitated?	❑ yes	❑ no
Is agitation achieved by air sparging?	❑ yes	❑ no
Could mechanical agititation be used to avoid the formation of carbonates due to air agitation?	❑ yes	❑ no
Are process baths continuously filtered?	❑ yes	❑ no
Are they batch filtered?	❑ yes	❑ no
Is sludge build-up in the tank a problem?	❑ yes	❑ no
Would increased filtering help?	❑ yes	❑ no
Can coarser filters be used? (Coarser filters hold more sludge & need replacement less often.)	❑ yes	❑ no
Is carbon filtering employed?	❑ yes	❑ no
Has the plant attempted to regenerate/purify solutions by cooling or freezing?	❑ yes	❑ no
Can the recovered solids be used in another process? (Copper sulfate crystals from regenerated etchant may be used for regenerating copper electroplating baths.)	❑ yes	❑ no
Does the plant use an alkaline stripper to clean photoresist material off of printed circuit boards?	❑ yes	❑ no
Is the stripper decanted or filtered periodically to remove polymer flakes and increase the useful life of the stripper?	❑ yes	❑ no

B. IMPROVING RINSE EFFICIENCY

Can a still rinse or drag-out tank be employed to recover drag-out and reduce loading on the rinse system?	❑ yes	❑ no
If recovered drag-out cannot be returned to the process bath, is it treated separately from the spent rinse water?	❑ yes	❑ no
Does the plant use spray or fog rinsing to reduce rinse water use?	❑ yes	❑ no
Do all the rinse systems utilize forced air or forced water as a means of agitating the rinse solution?	❑ yes	❑ no
If no, are workpiece racks agitated manually while submersed in the rinse solution?	❑ yes	❑ no
Does the plant have the available space to install multiple counter-current rinse tanks at any of the rinsing stations?	❑ yes	❑ no
Have the flow rates used on all the rinse systems been determined based on rinsing needs of the particular process chemistry? (Based on a drag-out value of 15 ml/ft² and a required dilution ratio of 1000:1, a single stage rinse tank should use approximately 4 gallons of rinse per square foot of board.)	❑ yes	❑ no

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WASTE MINIMIZATION: Process Modification

B. IMPROVING RINSE EFFICIENCY (CONT.)

Does the sum of each rinse system's estimated daily water usage approximate the average daily volume of wastewater treated? (If no, rinse water lines are most likely being left on even when the process line is not in operation.)	☐ yes	☐ no
Does the plant utilize the flow restrictors, flow control meters, or other devices intended to regulate the flow of water through all the rinse tanks?	☐ yes	☐ no
Does the plant generate rinse water effluents from rinse operations that follow mild and/or strong acid etching and cleaning processes?	☐ yes	☐ no
If yes, are the rinse solutions recycled for use in rinse systems following alkaline cleaning baths?	☐ yes	☐ no
Has the plant investigated the use of deionized water for rinsing?	☐ yes	☐ no
Would the use of deionized rinse water promote the potential for recycling?	☐ yes	☐ no

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OPTION GENERATION: Process Modification

Meeting format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Extending Process Bath Life		
Proper Rack Design/Maintenance		
Purer Anodes and Anode Bags		
Better Rinsing		
Deionized Water		
Proper Storage		
Lower Bath Concentration		
Increase Bath Temperature		
Wetting Agents		
Proper Board Withdrawal/Drainage		
Automation		
Recover Drag-out		
Monitor Bath Activity		
Control Bath Activity		
Mechanical Agitation		
Filtering/Impurity Removal		
B. Improve Rinse Efficiency		
Still Rinses		
Spray Rinsing		
Fog Nozzles		
Increase Agitation		
Counter-current Rinse		
Proper Equipment Design/Operation		
Reuse/Recycle Rinse		
Use Deionized Water		

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WASTE MINIMIZATION: Good Operating Practices

Is the production schedule varied to decrease waste generation? (For example, do you attempt to increase size of production runs and minimize cleaning by accumulating orders or production for inventory?) ❑ yes ❑ no

Describe _____

Are plant material balances routinely performed?	❑ yes	❑ no
Are they performed for each material of concern (e.g. solvent) separately?	❑ yes	❑ no
Are records kept of individual wastes with their sources of origin and eventual disposal? (This can aid in pinpointing large waste streams and focus reuse efforts.)	❑ yes	❑ no
Are the operators provided with detailed operating manuals or instruction sets?	❑ yes	❑ no
Are all operator job functions well defined?	❑ yes	❑ no
Are regularly scheduled training programs offered to operators?	❑ yes	❑ no
Are there employee incentive programs related to waste minimization?	❑ yes	❑ no
Does the facility have an established waste minimization program in place?	❑ yes	❑ no
If yes, is a specific person assigned to oversee the success of the program?		

Discuss goals of the program and results: _____

Has a waste minimization assessment been performed at the facility in the past? ❑ yes ❑ no

If yes, discuss: _____

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OPTION GENERATION: Good Operating Practices

Meeting format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
Increase Size of Production Run		
Perform Material Balances		
Keep Records of Waste Sources & Disposition		
Waste/Materials Documentation		
Provide Operating Manuals/Instructions		
Employee Training		
Increased Supervision		
Provide Employee Incentives		
Encourage Dry Cleanup		
Increase Plant Sanitation		
Establish Waste Minimization Policy		
Set Goals for Source Reduction		
Set Goals for Recycling		
Conduct Annual Assessments		

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10A

WASTE MINIMIZATION: Segregation, Reuse, Recovery, & Treatment

A. SEGREGATION

Segregation of wastes reduces the amount of unknown material in waste and improves prospects for reuse & recovery.

Are different solvent wastes segregated?	❑ yes	❑ no
Are aqueous wastes segregated from solvent wastes?	❑ yes	❑ no
Are spent solutions segregated from the rinse water streams?	❑ yes	❑ no

If no, explain: _____

Does the plant use chelators in any of the process baths?	❑ yes	❑ no
If yes, are waste streams that contain chelators segregated from other waste streams prior to treatment? (Waste streams that contain chelators often require additional treatment. This additional treatment will cause a greater volume of wastewater treatment sludge to be generated.)	❑ yes	❑ no

B. CONSOLIDATION/REUSE

Are many different solvents used for cleaning?	❑ yes	❑ no
If too many small-volume solvent waste streams are generated to justify on-site distillation, can the solvent used for cleaning be standardized?	❑ yes	❑ no
Is spent cleaning solvent reused?	❑ yes	❑ no
Does the plant generate spent alkaline and/or acidic baths that can be used for elementary neutralization in the industrial waste treatment process?	❑ yes	❑ no

Describe which measures were successful: _____

Has off-site reuse of wastes through Waste Exchange services been considered?	❑ yes	❑ no
Or reuse through commercial brokerage firms?	❑ yes	❑ no

If yes, results: _____

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WASTE MINIMIZATION: Segregation, Reuse, Recovery, & Treatment

C. On-Site Recovery

On-site recovery of solvents by distillation is economically feasible for as little as 8 gallons of solvent waste per day.

Has on-site distillation of the spent solvent ever been attempted? ❑ yes ❑ no
If yes, is distillation still being performed? ❑ yes ❑ no

If no, explain: _____

_____

_____

Does the plant generate waste streams that contain valuable process chemicals or metals? ❑ yes ❑ no
If yes, does the plant currently utilize any recycling technologies to recover valuable process chemicals or metals? ❑ yes ❑ no
Does the plant utilize treatment technologies to recycle rinse water? ❑ yes ❑ no
If no, has the plant assessed the potential for developing a closed loop rinse water system? ❑ yes ❑ no

Discuss the results of recycling: _____

_____

_____

D. Alternative Treatment Technology

Does the plant operate an industrial waste treatment facility? ❑ yes ❑ no
If yes, does the treatment facility produce a wastewater treatment sludge that is handled as a hazardous waste? ❑ yes ❑ no
Has the plant evaluated the use of alternative treatment chemicals (such as caustic soda instead of lime or polyelectrolytes instead of alum or ferric chloride) to identify those that generate the lowest volume of sludge? ❑ yes ❑ no
If yes, has the plant evaluated the use of an alternative treatment system that produce less residual waste than the existing treatment facility? ❑ yes ❑ no

APPENDIX A
CASE STUDIES OF PRINTED CIRCUIT BOARD MANUFACTURING PLANTS

In 1986 the California Department of Health Services commissioned a waste minimization study (DHS 1987) of three printed circuit (PC) board manufacturing firms, called plants A, B and C in this guide. The results of the three waste assessments were used to prepare waste minimization assessment worksheets to be completed by other printed circuit board manufacturers in a self-audit process.

The three printed circuit board manufacturing plants were chosen for their willingness to participate in the study, their applicability to the study's objectives, and the potential usefulness of the resulting data to the industry as a whole. The waste minimization assessments were concerned with waste generated within the plant boundaries and not with waste derived from printed circuit board application or disposal of board parts.

This Appendix section presents the results of the assessments of Plants A, B and C and the waste minimization options either already in use or being considered for use by the firms.

The waste minimization assessments were conducted according to the description of such assessments found in the "Introduction: Overview of Waste Minimization," in this guide. The steps involved in the assessments were (see also Figure 1):

- Planning and organization
- Assessment phase
- Feasibility analysis phase

The fourth phase, Implementation, was not a part of these assessments since they were conducted by an outside consulting firm. It was left to the printed circuit board manufacturers themselves to take steps to implement the waste minimization options that passed the feasibility analysis.

PLANT A WASTE MINIMIZATION ASSESSMENT

Planning and Organization

Planning and organization of the assessment was done by the consulting firm with the assistance of personnel from the PC board manufacturing firm. Initial contact was made with the PC board manufacturer's plant operations manager, a high level manager who could provide the company's commitment to cooperate in the assessment and provide all the necessary facility and process information. The goal of this joint effort was to conduct a comprehensive waste minimization assessment for the plant. Under different circumstances, in a company with its own on-going waste minimization program, goals could be set to target a specific amount or type of waste to be reduced; or to conduct a waste minimization assessment each year; or other goal. The waste assessment task force in the case of Plant A consisted of the consultants working together with the plant manager. This task force also functioned as the assessment team.

Assessment Phase: Process and Facility Data

Initial discussions by telephone between the consultants and the plant manager were used to request process and facility information prior to a site visit. These discussions also served to identify particular waste streams of concern to plant managers.

At the site visit, the plant operations manager and consultants met to review the facility's operations and its potential target waste streams. The manager conducted a facility tour and introduced the consultants to process managers and workers involved in materials and waste handling. Some of these people were interviewed to obtain information about specific procedures used at the plant.

FACILITY DESCRIPTION

Plant A is a prototype circuit board manufacturer that specializes in jobs involving limited production and fast turnaround. Manufacturing operations include drilling and routing, layering (for multilayer boards), photoresist printing, plating, etching, and stripping.

PROCESS DESCRIPTION

Figure A-1 is a floor plan of the plant's plating, etching, and stripping operations. The numbers listed on the floor plan represent the identification number for each process bath and rinse tank. Tables A-1, A-2, and A-3 provide information on the plant's operations. Table A-1 describes each process bath used at plant A and Table A-2 describes each rinse system used at the plant.

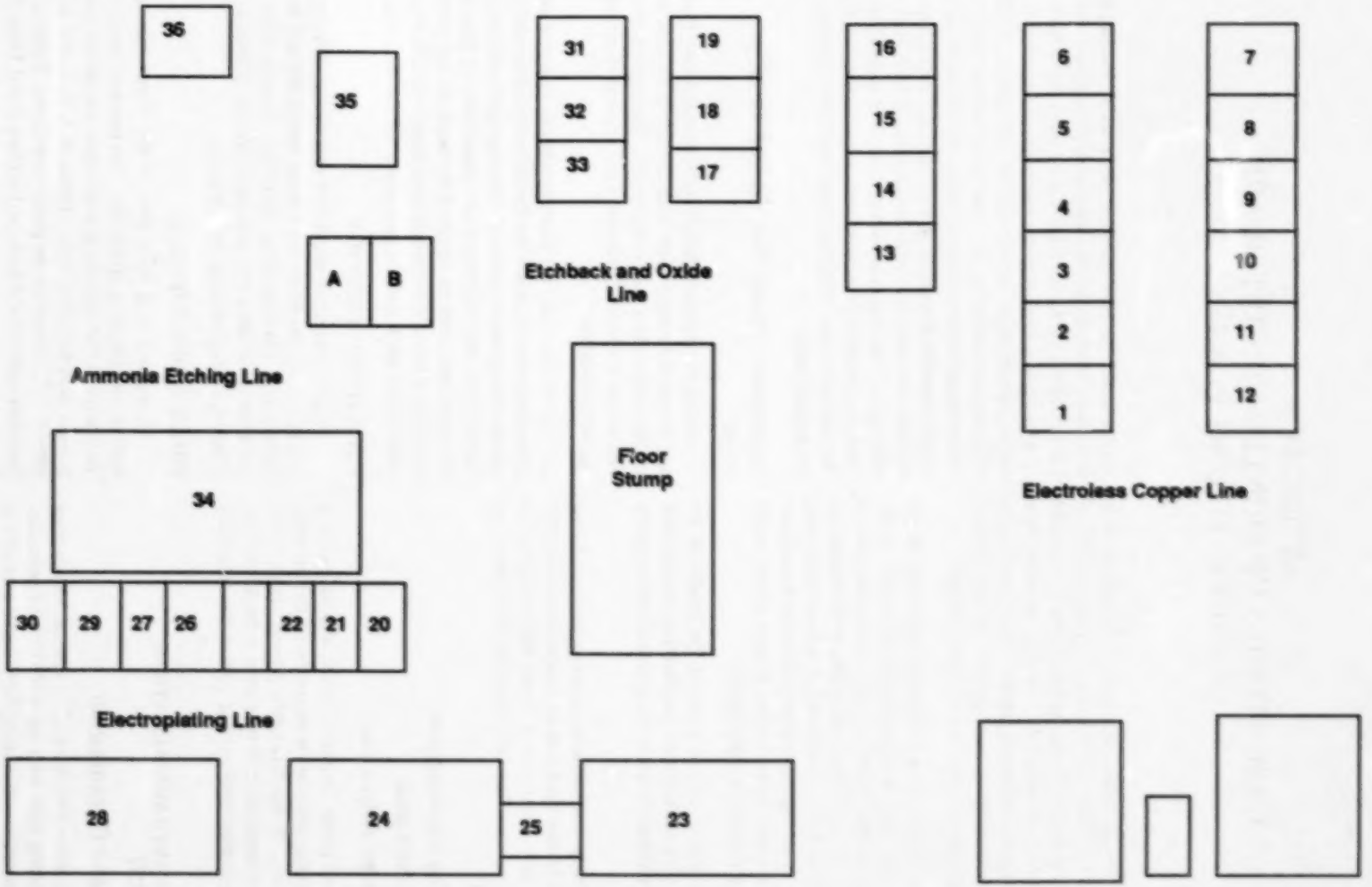

Figure A-1. Plant A's Plating Etching and Stripping Operations

Table A-1. Process Bath Information

PROCESS BATH/ IDENTIFICATION NUMBER	PROCESS BATH VOLUME (gallons)	METHOD OF DISPOSAL IN TANK	FREQUENCY OF DUMPS
Cleaner-Conditioner/1	30	To treatment	2 weeks
Sulfuric-Peroxide Etch/3	30	To treatment	4 weeks
Catalyst Premix/5	30	To treatment	2 weeks
Catalyst/6	30	---	---
Accelerator/8	30	To treatment	2 weeks
Electroless Copper/11	30	---	---
5% Sulfuric Acid/12	30	To treatment	2 weeks
100% Sulfuric Acid/13	30	To treatment	1 week
Neutralizer Etchback/15	30	To treatment	4 weeks
Brown Oxide/17	30	---	---
Ammonium Biflouride/19	30	To treatment	4 weeks
Metex Cleaner/20	20	To treatment	1 week
10% Sulfuric Acid/22	400	To treatment	1 week
Copper Gleam/23	400	---	3 years
Copper Gleam/24	400	---	3 years
10% Fluorboric Acid/27	20	To treatment	2 weeks
Tin Lead/28	400	---	3 years
Resist Stripper/31	30 disposal	Off-site	2 weeks
Tin Immersion Conditioner/33	30	Reclaimed by supplier	---
Ammoniated Etch/34	--- supplier	Reclaimed by	4 weeks
Reflow Oil/36	30	Off-site disposal	---

WASTE DESCRIPTION

Production activities that generate hazardous waste are the plating, etching, and stripping processes. The sources of waste from these activities are rinsing operations, spent process bath dumping, industrial waste treatment, and equipment cleanout. Table A-3 describes the hazardous wastes produced at the plant.

Spent Chemical Bath

When a process chemical bath becomes too contaminated or diluted for use (spent), it is removed from the process tank. The spent chemical bath is then either containerized for reclaim by the manufacturer, containerized for off-site disposal, used as a neutralization chemical in the industrial waste treatment system, or dumped into the wastewater collection sump. The chemical baths are changed periodically according to the plant's current time schedule. This schedule was developed by Plant A based on its experience with various process baths.

Only two of the spent bath handling methods contribute to the amount of hazardous waste generated at the plant. These methods are containerizing waste for off-site disposal and dumping of spent chemical baths into the wastewater sump. Two process chemical baths are containerized for disposal: (1) photoresist stripper and (2) reflow oil. Approximately 55 gallons of waste stripper are generated monthly. Plant A did not estimate the volume of waste reflow oil generated each month.

Photoresist stripper waste is generated at the conditioning and stripping line. The stripper is used in a 30-gallon tank where circuit boards are immersed to strip off the remaining photoresist material. The chemical bath is changed approximately every 2 weeks. The resultant stripper waste is highly alkaline with a pH over 12. The waste stripper contains a polymer residue which, when agitated, remains suspended in the solution.

Reflow oil is used to enhance the formation of a smooth, uniform film of solder onto printed circuit boards. The reflow oil bath is maintained at an elevated temperature during use. When the bath becomes spent, it is containerized for off-site disposal. Analytical data for the spent oil were not available.

Table A-2. Rinse System Information

Rinse System/ Number	Rinse Water Flow Rate	Number Of Tanks	Counter Current System	Process Bath(s) Preceding Rinse System (Y/N)	Estimated Daily Water Use
Dip Rinse/12	16 gal/min	one	no	Cleaner/ conditioner	1500 gallons
Dip Rinse/4	16 gal/min	one	no	Sulfuric/ peroxide etch	1500 gallons
Dip Rinse/7	16 gal/min	one	no	Catalyst	1500 gallons
Dip Rinse/9	16 gal/min	one	no	Accelerator	1500 gallons
Dip Rinse/10	16 gal/min	two	no	Rinse tank #9	1500 gallons
Dip Rinse/14	16 gal/min	one	no	Sulfuric acid	500 gallons
Dip Rinse/16	16 gal/min	one	no	Neutralizer etchback	500 gallons
Spray Rinse/21	1.5 gal/min	one	no	Metex cleaner	---
Drag-out/25	---	one	no	Gapper gleam	---
Spray Rinse/26	1.5 gal/min	one	no	Sulfuric acid	---
Drag-out/29	---	one	no	Fluorboric acid	---
Spray Rinse/30	1.5 gal/min	one	no	Drag-out tank #29	---

Table A-3. Hazardous Waste Data

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
Industrial Waste Treatment Sludge	2,400 gal.	off-site metal reclamation	$1.00/gal	$2,400
Photoresist Stripper	720 gal.	off-site disposal	---	---
Reflow Oil	---	off-site disposal	---	---
Nitric Acid	120 gal.	off-site disposal	---	---
Copper Sulfate Crystals	---	off-site disposal	---	---

The plant's standard practice for dumping spent chemical baths into the wastewater sump is to transfer waste chemicals to one of the two metering tanks (tanks A and B in Figure A-1). These tanks slowly discharge waste chemicals into the waste sump. The purpose for slowly feeding the spent bath chemicals into the wastewater sump is to prevent surges in the waste stream pH or metals content. These two metering tanks have not, however, been in operation since July 1986. The present practice is to manually dump the spent baths into the collection sump. Plant A personnel indicated that this practice causes a fluctuation in the pH of the waste stream entering the treatment system.

Copper sulfate crystals are generated when some of the process baths are taken off-line. The crystals form in the process bath as the copper content increases. Before the process baths are dumped into the wastewater sump, the crystals are removed and containerized as a solid waste since they cannot be fed into the treatment system.

Rinsing Operations

Rinsing operations associated with the chemical process lines are the major source of wastewater at Plant A. Plant A estimates that approximately 10,000 gallons of wastewater are generated each day. The rinse operations contribute to hazardous waste generation because waste rinse water carries away chemicals which are then removed by treatment at the industrial waste treatment plant. The sludge that is generated from this treatment is handled as a hazardous waste.

Plant A uses nine dip rinse tanks and three spray rinse tanks. All rinse water used at Plant A is deionized onsite prior to use. All but two of the rinse tanks are plumbed directly to the wastewater treatment system through a 500-gallon collection sump. The other two are batch dump tanks which require manual dumping into the sump.

Discussions with facility personnel indicate that water flows through the dip rinse tanks only when the process line associated with the tank is in operation. However, during both visits, the assessment team observed water flowing through several rinse tanks even when the process line was not being operated. The flow rate of water through each dip rinse tank was measured to be approximately 16 gallons per minute. This was measured by closing the drain line, turning on the feed water for 20 seconds, measuring the water level rise in the rinse tank, and calculating the volume of water that entered the tank during the time period. The flow rate of water through the spray rinse tank has been estimated by the assessment team to be approximately 1.5 gallons per minute.

Industrial Wastewater Treatment

Plant A's industrial waste treatment facility treats all wastewater before discharging it to the San Jose/Santa Clara Water Pollution Control Plant. Plant A's treatment facility removes metals and adjusts the pH of the wastewater to meet discharge requirements set by the water pollution control plant. The maximum allowable concentration of metals in the discharged effluent, as set by the San Jose/ Santa Clara Water Pollution Control plant, are as follows:

- Chromium 1.0 mg/L
- Copper 2.7 mg/L
- Cyanide 1.0 mg/L
- Lead 0.4 mg/L
- Nickel 2.6 mg/L
- Silver 0.7 mg/L
- Zinc 2.6 mg/L

The treatment process includes metal reduction, neutralization, and flocculation. The treatment plant is located outside the main building in a fenced and curbed area. The metal hydroxide sludge generated by the treatment process is a hazardous waste.

Chemical treatment is performed in three separate tanks; the wastewater then goes through sludge separation and dewatering. Approximately 10,000 gallons of wastewater are treated each day. Wastewater characterization data were not provided by Plant A. The incoming wastewater is pumped from the collection sump to the first tank where ferrous sulfate and sulfuric acid are added. Ferrous sulfate is used to reduce the copper to its precipitable form. The sulfuric acid is used to maintain the pH between 2.0 and 3.0 during the ferrous sulfate reaction. The waste is then neutralized with alum and sodium hydroxide. The alum causes the suspended solids to collect, forming larger particles, and the sodium hydroxide raises the pH to approximately 9.0. A polyelectrolyte coagulant is then introduced to aid in the flocculation of the contaminants. The polyelectrolyte causes the precipitated contaminants to congeal into large flakes which can be settled out of the waste stream. Plant A personnel provided information on the quantities and costs of treatment chemicals used each month (Table A-4).

Table A-4. Quantities and Costs of Treatment Chemicals - Plant A

Chemical	Monthly Usage	Cost/Unit	Cost/Month
Ferrous sulfate	850 lbs	$0.33/lb	$280
Alum	850 lbs	$0.47/lb	$400
Sodium hydroxide	200 gallons (30% solution in winter)	$0.55/gal	$110 winter
	(50% solution in summer)	$0.92/gal	$185 summer
Polyelectrolyte	3 lbs	$7.50/lb	$ 22

Total $812/in winter

$887/in summer

The wastewater treatment sludge that is settled out of the effluent waste stream is transferred to the sludge dewatering unit, and the effluent is discharged to the San

Jose/Santa Clara Water Pollution Control Plant. Sludge is dewatered in a bag filter that increases its solids content to 11 percent. The dewatered sludge is transferred into 55-gallon drums and stored for pickup by a metal reclaimer (World Resources Company). Plant A plans to use large storage bags in the future which will hold the equivalent of four 55-gallon drums. Plant A estimates that four drums of industrial waste sludge are generated each month. The sludge is considered a hazardous waste because of the copper content.

Analytical data for the sludge were obtained from World Resources Company of Phoenix, Arizona. World Resources analyzes a sample from each load of sludge transported to them for metal reclamation. The data provided by World Resources are as follows:

Percent solids	11%
Metal content in pounds per dry ton	
Copper	195
Nickel	6
Tin	46
Iron	399
Zinc	9
Lead	23
Chromium	20

Equipment Cleanout

The primary sources of hazardous waste associated with equipment cleanout are the cleaning of the copper etching tank, cleaning of tanks used in the electroplating line, and cleaning of electroplating racks. This equipment is cleaned by using nitric acid. Plant A estimates that one 55-gallon drum of waste nitric acid is generated every 6 months. The waste nitric acid has too low a pH and too high a copper content to be treated at the plant's wastewater treatment system. Analytical data on the waste nitric acid were not available from Plant A.

Other cleaning activities, such as floor washing and chemical bath tank rinsing, generate waste streams that discharge into the wastewater collection sump. According to Plant A personnel, these waste streams make up a small portion of the chemicals that enter the treatment system.

Assessment Phase: Option Generation

The consultants reviewed the plant operations data obtained prior to and during the site inspection. They developed a set of waste minimization options based on this information and on information in the literature. These options were screened for their effectiveness in reducing waste and for their future implementation potential. The plant manager participated in this screening, with the result that there was general consensus on the list of recommended options.

SOURCE REDUCTION

The following paragraphs describe the application and use of source reduction measures to various waste streams at Plant A.

Material Substitution

Opportunities for material substitution that apply to Plant A include (1) using process chemistries that can be recycled or treated prior to discharge to the publicly owned treatment works (POTW) and (2) using chemistries that have less impact on sludge generation. Process chemistries that Plant A currently containerizes for off-site disposal include spent reflow oil and nitric acid waste. Several reflow oil products are available that, when spent, either can be returned to the supplier for recycling or can be treated by the facility prior to discharge to the POTW. Plant A could eliminate a hazardous waste stream by replacing its present reflow oil with a recyclable or treatable reflow oil.

Nitric acid waste, which is generated from the cleaning of electroplating racks, can also be eliminated by using an alternative cleaning solution. One chemical supplier offers an electroplating rack cleaning solution that can be regenerated. The metal stripped off of racks can be plated out in a tank equipped with a cathode and an anode. The metallic sludge then settles to the bottom of the cleaning tank where it can be removed and mixed with the wastewater treatment sludge. Once the cleaning solution becomes spent, it can be treated in the plant's industrial waste treatment system before being discharged to the POTW. The use of recyclable cleaning solution will eliminate the generation of waste nitric acid. The metallic sludge that is generated can be sent to a metal reclaimer along with the wastewater treatment sludge.

The use of non-chelated process chemistries can reduce the volume of sludge generated during wastewater treatment. Plant A uses ferrous sulfate to treat its wastewater. The ferrous sulfate is used to break down chelators so that metals can be precipitated. The iron in ferrous sulfate also precipitates as a metal hydroxide and contributes to sludge volume. The analytical data for Plant A's industrial waste treatment sludge indicate that iron contributes approximately 57 percent of the total metal content of the sludge. If all the iron precipitates as metal hydroxide, the iron hydroxide contributes 34 percent of the total dry weight of the sludge. If plant A used non-chelated process

chemistries, ferrous sulfate treatment could be eliminated and sludge generation could be reduced. Most chemical suppliers offer non-chelated process chemistries or chemistries with mild chelators that do not require ferrous sulfate treatment. Plant A should consult with chemical suppliers to identify alternative process chemistries that can be used so that ferrous sulfate treatment can be minimized.

Rinse Water Reduction

Although rinse water is not a hazardous waste, the treatment of this waste produces a sludge that is a hazardous waste. Since the volume of the sludge generated by treatment is a function of the volume of wastewater treated as well as the concentration of contaminants in the waste, the plant can reduce the volume of sludge generated by reducing its rinse water generation. Several rinse reduction options are available to Plant A that can reduce the volume of wastewater requiring treatment. Multiple stage rinse water systems were not evaluated because not enough space is available at Plant A's facility.

Rinse Tank Operations

Plant A now operates several of its dip rinse tanks as flow-through tanks. Deionized water is plumbed into the tank during operation and the overflow is plumbed to the collection sump. Each of the rinse tanks holds approximately 30 gallons of rinse water, and the flow of water through each tank is approximately 16 gallons per minute. PRC believes that the plant could modify its operation of these rinse tanks to reduce the volume of wastewater generated. Two options are available for Plant A: (1) the dip rinse tanks can be operated as batch rinse tanks or (2) the flow rate through the tanks can be reduced.

If these seven dip rinse tanks were operated as batch rinse tanks (which means they would operate as stagnant rinse tanks that are emptied between rinse operations and then refilled with deionized water), Plant A could reduce its rinse water generation significantly. Table A-4 shows the volume of rinse water generated by Plant A and the volume that would be generated if the seven dip rinse tanks were operated as batch rinse tanks. The values for the time water is running and for the number of workpiece racks processed daily were provided by Plant A personnel. This option assumes that each rinse tank can provide adequate rinsing of one process rack when filled with fresh deionized water. Plant A did not provide the auditors with information on the required operating parameters of the rinse systems. Therefore, the impact of batch rinsing on the efficiency of the rinsing operations could not be assessed. The following example, however, illustrates the feasibility of batch rinsing.

The equation for determining the volume of rinse water needed to rinse a full workpiece rack is as follows:

$$Q = D(Cp/Cn)$$

Where Q = rinse tank flow rate
D = drag-out rate
Cp = concentration of salts in process solution
Cn = allowable concentration in rinse solution

Several assumptions must be made to use this equation to illustrate the potential for operating the rinse tanks as a batch rinse system. These are as follows:

- The concentration of chemicals in the rinse solution cannot exceed 1/1000 of the concentration of chemicals in the process bath. This value is a common parameter used in the electroplating industry for rinse water contaminant concentration.
- The drag-out rate of chemicals used for manufacturing printed circuit boards is approximately 15 ml/ft2 of board. This value is a standard approximation used for estimating drag-out created by a printed circuit board (Foggia, 1987).
- An average workpiece rack holds approximately 2.5 ft3 of boards (example: 30 4-inch by 3-inch boards).

The drag-out rate for each workpiece rack is:

15 ml x 2.5 ft3 = 37.5 ml.

Converted to gallons, drag-out equals 0.01 gallon.

By substituting the values into the equation:

$$0.01 \text{ gallon} \times \frac{1000}{1} = 10 \text{ gallons}$$

10 gallons of fresh rinse water will provide adequate rinsing under the operating parameters previously described. Since the rinse tanks hold approximately 30 gallons of rinse water, theoretically, a full tank of fresh water would provide adequate rinsing without operating the tank as a flow-through tank. Workpiece rack agitation or air spargers can be used to improve efficiency to assure adequate rinsing in the batch rinse tank.

Although using the dip rinse tanks as a batch process can provide significant reductions in wastewater generation, there may be several process lines for which this is not feasible because of the chemistry of the process. However, even if some of the tanks must operate as flow-through rinse systems, the volume of deionized water used can still be reduced for these tanks. The same equation can be used to demonstrate that the present flow rate used in the rinse tanks may be excessive.

The equation can be rearranged to indicate the ratio of process bath concentration to rinse solution concentration, as follows:

$$\frac{Q}{D} = Cp/Cn$$

The same drag-out volume (0.01 gallon) will be used, and it will be assumed that the process rack remains in the rinse tank for 3 minutes. The ratio of the process bath concentration to rinse solution concentration is as follows:

$$\frac{16 \text{ gals/min} \times 3 \text{ min}}{0.01 \text{ gal.}} = 4{,}800$$

Therefore, to justify the present rinse water flow rate, the concentration of chemicals in the rinse solution can only reach 1/4,800 or 2/10,000 of the concentration of chemicals in the process bath before rinse efficiency is reduced. As previously stated, the electroplating industry usually allows rinse water concentrations to reach 1/1000 the concentration of chemicals in the process tank. Plant A should consult chemical manufacturers' representatives and perform experiments to determine the proper flow rate for its rinse tanks if batch operation is not feasible.

By calculating the flow rate necessary to maintain the rinse water at an acceptable chemical concentration , Plant A may find that the 16 gallon per minute flow rate presently used is too high. In addition, the use of air spargers or work piece rack agitation should improve rinse efficiency and allow for use of lower rinse water flow rates.

Rinse Water Flow Controls

Plant A presently turns on the rinse water in-flow valves manually. When the process line is in operation, plant personnel turn on the water for all the rinse tanks and then turn the water off after the production process is complete. However, the consultants observed that rinse tanks were left on even when the process line was not in use. The use of automated flow controls would be helpful for ensuring that rinse water is not left running and for controlling the flow rate when the rinse water is turned on.

The plant should consider installing pH meters in each of the rinse tanks to control the flow of water through the rinse systems. The meters should be set to turn the fresh water feed valve on when the chemical concentration in the rinse gets too high. If the required pH range for each rinse tank is determined, the meters can be set to turn on the water automatically. When the rinse tank solution pH reaches the maximum allowable level to provide efficient rinsing, the meter will send a signal that activates a valve on the influent line. When the rinse solution again reaches an acceptable pH, the pH meter will send a signal that turns off the water feed valve.

Flow restrictors can also be used to reduce flow rates. A limiting orifice or similar flow-restricting device can be installed in the water line to each tank to reduce the flow rate to each tank. Plant A uses approximately 2-inch diameter piping for its rinse inflow lines. This piping may be oversized for the pressure on the line and the required flow rate. The use of flow restrictors, therefore, may provide better controls over the rate of rinse water usage. One circuit board manufacturer who installed pH meters, flow restrictors, and other water reduction devices, such as foot pedal pressure switches, was able to reduce water usage by two thirds.

Process Bath Drag-Out

Process bath chemicals are carried into the rinse water when the racks that hold the printed circuit boards are removed from a process bath tank and placed in a dip rinse tank. This is performed manually at Plant A. The operator removes the rack, briefly holds it above the process bath tank, and submerges the rack into the rinse tank. The consultants personnel observed plant personnel performing this operation and found that the racks are quickly removed from the process bath and held over the process bath tanks for less than 10 seconds. This procedure allows excessive chemicals to enter the waste rinse water stream. Actual drag-out volumes were not available from Plant A, however.

The manner in which racks are removed from process baths will significantly affect the amount of drag-out carried into the rinse tanks. Slow removal of workpieces causes a much thinner film of process chemicals to adhere to the workpiece surface. This effect is so significant that most of the workpiece drainage time should be used to remove the workpiece rack from the process bath. The consultants observed that Plant A personnel remove racks in one quick movement. We suggest that Plant A train its personnel to remove racks in a slow, smooth manner. Plant A could also improve the drag-out recovery efficiency of the process lines by installing a bar or rail above the process tank so that the racks can be hung and allowed to drain longer.

The auditors did not predict the drag-out volume that can be recovered by removing racks at a slower rate and allowing racks to drain for a longer period of time. However, the savings realized by reducing drag-out losses include reducing process chemical purchases and reducing wastewater treatment sludge generation. Plant A can determine the effectiveness of these drag-out reduction techniques by holding the racks over a collection pan after removing them. The volume of drag-out that can be recovered after removing racks at various rates and allowing racks to drain for various lengths of time can then be measured and the optimal removal rate and drainage time can be determined.

Equipment Cleanout

Plant A generates approximately 55 gallons of waste nitric acid every 6 months from cleaning out the electroplating tanks and from cleaning the electroplating racks. Plant A may be able to reduce the volume of nitric acid generated by modifying the existing cleaning methods.

One method for reducing the volume of waste nitric acid produced is to set up a workpiece rack cleaning line with several small tanks of nitric acid. The cleaning line is then used like a multi-stage rinse system. The first tank contains the most contaminated nitric acid solution and the final tank in the cleaning line contains the freshest nitric acid. When the first tank no longer performs adequate initial cleaning, it is containerized for disposal (or used as initial cleaning solution for tank cleanout). Then the second tank in the cleaning line becomes the first. The empty tank is then filled with fresh nitric acid and it becomes the last tank in the cleaning line.

The use of a multi-stage rinse system can provide significant reductions in waste cleaning solution generation. One printed circuit board manufacturing plant visited by the consultants uses a five-stage multiple tank cleaning line and only generates approximately 15 gallons of waste nitric acid each 6 months.

Chemical Process Baths

The chemical load on wastewater can be reduced by operating the process baths at lower concentrations. A manufacturer's recommendations for chemical concentrations in process baths are not always appropriate. We recommend that Plant A evaluate the efficiency of the concentration parameters of its present chemical process bath to determine if these concentrations can be reduced. By reducing the concentration of chemicals in a process bath, the plant will minimize the chemical load in the wastewater when these baths are dumped. This reduction will also reduce the chemical concentration in the rinse water by minimizing drag-out chemical loses.

One method of reducing process bath chemical concentrations is to operate fresh baths at lower concentrations than older baths. Plant A can accomplish this by gradually increasing the chemical concentration in the process bath as it gets older. This practice can reduce the chemical concentration of the drag-out from fresh baths and also extend the life of some process baths.

Waste Segregation

The wastewater generated at Plant A is plumbed or manually dumped into a 500-gallon collection sump. Therefore, all wastes that can be treated on-site are mixed prior to treatment. This practice may cause excessive use of treatment chemicals and an increase in the volume of sludge generated. Waste segregation may reduce the use of treatment chemicals and the generation of sludge in two areas: the non-contact cooling water used for the copper etch machine and the waste streams generated by processes that contain chelating chemistries.

Plant A personnel indicated that the cooling water system used in the copper etcher is a once-through system, with the effluent discharged to the collection sump. If the system were operated as a closed loop system, there would not be an effluent waste stream. Also, since this water is used as non-contact cooling water, the effluent that is now generated by the system may not require treatment. The effluent, therefore, could possibly be discharged directly to the sanitary sewer, if permitted by the Publicly-Owned Treatment Works (POTW).

The use of a closed loop cooling system would lead to reductions in water and sewer fees, treatment chemical use, and sludge generation. Direct discharge of non-contact cooling water to the sanitary sewer would result in savings from reduced treatment chemical use and sludge handling. The consultant was unable to obtain estimates on the volume of water used in the etcher cooling system; therefore, specific values for savings cannot be presented.

The primary purpose of the treatment system used at Plant A is to remove metals from the waste stream so that the discharged effluent can meet San Jose/Santa Clara Water Pollution Control Plant pretreatment standards. The highest metals concentration in the wastewater is copper, and the treatment system is designed to remove the copper through a ferrous sulfate reduction process. The ferrous sulfate process is designed to break down chelators that keep metals in solution past their normal solubility limit. The ferrous sulfate contributes significantly to the volume of sludge generated in the wastewater treatment process. Analytical data indicate that iron content in the sludge is 399 pounds per dry ton of solids. Assuming that all the iron precipitates as a hydroxide, iron hydroxide contributes 34 percent of the total dry weight of solids in the sludge. If there is a direct relationship between solids content and total sludge volume, the plant could reduce sludge volume by 34 percent by eliminating iron from the waste treatment system.

Several options are available to eliminate or reduce the amount of ferrous sulfate used in the treatment process. These include: (1) eliminating the use of chelated process chemistries, (2) using process chemistries that only contain mild chelators, (3) segregating waste streams that contain chelators from other waste streams, and (4) segregating waste streams that contain copper from other waste streams. Plant A was unable to identify which process baths use chelators or what type of chelators are used. Therefore,

specific recommendations for waste segregation cannot be developed. However, several waste segregation options are described.

Use of non-chelated process chemistries or mild chelators may allow Plant A to eliminate the use of ferrous sulfate. Since the primary purpose of ferrous sulfate is to break down chelators so that copper can be precipitated from the wastewater, non-chelated process chemistries would allow the use of an alternative precipitant such as caustic soda. Mild chelators, such as ethylenediamine tetraacetic acid (EDTA), can be broken down through pH reduction. Therefore, if EDTA is used where chelators are needed, such as in an electroless copper bath, ferrous sulfate may not be required for wastewater treatment.

Mixing waste streams that contain chelating agents with waste streams that are non-chelated appears to cause a significant increase in the amount of treatment chemicals used, and should be avoided when possible. Ferrous sulfate use can also be reduced by segregating waste streams. According to Plant A personnel, the sources of copper that enter the wastewater are (1) the copper drag-out tank, (2) spray rinse tank 29, and (3) dip rinse tanks 9 and 10. If these waste streams were segregated from the rest of the wastewater, ferrous sulfate treatment would only be necessary for a percentage of the waste. This could be done on a batch treatment basis if a holding tank is used to store the waste until treatment. The remaining wastewater could have metals removed by neutralization and precipitation with caustic soda. This would reduce the amount of treatment chemicals used at the facility. If other waste streams contain chelators, these could also be segregated from the rest of the waste stream.

RECYCLE AND RESOURCE RECOVERY ALTERNATIVES

Recycling and resource recovery includes the direct use of a waste stream or the recovery of materials from a waste stream. Plant A appears to handle many of its waste streams in this manner. Spent sulfuric acid is used in the wastewater treatment system, and several chemical process baths are returned to the manufacturer when they become spent. This chapter describes several additional recycling and resource recovery techniques that may be implemented by Plant A.

Stripper Waste

Plant A personnel indicated that the plant's stripper waste is an alkaline solution that could be reused or used in the treatment system if the polymer residue could be removed. The plant could use a filter or decantation system to separate the residue from the waste solution. Also, the volume of stripper waste generated can be reduced significantly by using a multiple tank stripper system. This type of system allows the first stripper tank (the one with the most contaminated stripper solution) to be used for a longer period of time because the second stripper tank will be used for additional photoresist stripping. Therefore, the photoresist stripper does not have to be replaced every 2 weeks. When the first tank is dumped, the second tank becomes the first. Fresh resist stripper is then added to the second tank.

Rinse Water Recycling

Currently, Plant A plumbs all its rinse water effluent directly into the collection sump. However, the plant may be able to recycle some of the rinse water solutions. For example, rinse systems that follow an acid process chemical bath, such as a peroxide/sulfuric acid etch, can sometimes be used for feed water to a rinse system that follows an alkaline cleaning bath. Implementation of such a system, however, should be done only after careful testing to make sure that addition of acid rinse water to the alkaline rinse bath does not cause problems with metal hydroxide precipitation on clean parts.

The configuration of Plant A's process lines may allow some of these rinse systems to be plumbed together in series. For example, rinse tank 14, which follows a sulfuric acid bath, could be plumbed into rinse tank 16, which appears to follow an alkaline cleaning bath. Based on data of the existing water used, rinse tanks 14 and 16 both use approximately 500 gallons each day. If 100 percent of the water used in rinse tank 14 could be used for rinsing operations in tank 16, 500 gallons of water could be saved each day. The plant would also reduce the volume of wastewater treated each day by 500 gallons and could, therefore, reduce treatment chemical usage and sludge generation. Rinse water could also be recycled if the rinse tanks were operated on a batch process.

Copper Sulfate Crystals

Plant A personnel indicated that they were unsure of how to handle the copper sulfate crystals generated at the plant. Currently, these crystals are disposed of offsite as a hazardous waste. One option available to the facility is to mix the crystals with the industrial waste treatment sludge. Since this sludge is sent to a reclaimer, the copper content in the crystals may bring Plant A a larger payment on reclaimed copper. This practice will also prevent Plant A from accumulating containers of crystals.

TREATMENT ALTERNATIVES

Waste reduction through alternative treatment can be achieved by modifying a treatment system to reduce the

volume of hazardous waste generated. One of the treatment alternatives available to Plant A is segregation of waste streams, which is described earlier in this report. Another treatment alternative available to Plant A is sludge dewatering.

Sludge Dewatering

Wastewater treatment sludge generated at Plant A is dewatered by a gravity filter system. Although this type of dewatering can remove some of the free water in the sludge, it is not as effective as mechanical dewatering. Analytical data for the waste treatment sludge show that the gravity filter system can increase solids content to 11 percent. Mechanical dewatering equipment can achieve a solids content up to 35 percent for most industrial waste sludge. Figure A-2 shows the decrease in sludge volume that can be achieved by increasing solids content. The figure shows that increasing the solids content from 10 percent to 35 percent reduces sludge volume from 80 gallons to 20 gallons.

Plant A now removes the sludge from the filter system and allows it to air dry in open drums. This has significantly reduced the sludge volume, according to Plant A personnel. However, this method of dewatering will not work during the rain season, and it also presents problems for complying with the 90-day accumulation limits placed on hazardous waste generators. Therefore, the use of a mechanical dewatering system may be beneficial for reducing sludge volume and also for complying with hazardous waste regulations.

Assuming a direct correlation between wastewater volume and sludge volume, Plant A could also reduce its sludge generation by 80 percent. This would equal three drums less each month at a savings at $50 per drum, or $150. Total savings for operating each rinse tank as a batch rinse system could be as great as $1020 each month.

Savings from reducing the flow rate of water through each rinse tank depends on the minimum flow rate that can be used to maintain adequate rinsing. In the Rinse Water Reduction section, it was shown that the present flow rate of 16 gallons per minute creates a ratio of process bath concentration to rinse solution concentration of 5,000 to 1. For illustration purposes, assume the flow rate could be reduced to 12 gallons per minute; ratio would be reduced to 3750 to 1. The rinsing requirements for Plant A rinse systems were not available to the consultants. However, since the standard ratio of process chemical concentration to rinse solution concentration used in the electroplating industry is approximately 1000 to 1, a 25 percent reduction in flow rate, which produces a 3750 to 1 ratio, appears achievable. If the flow rate could be reduced by 25 percent: (1) water and sewer fee savings would be $46 per month (based on a reduction in water usage of 34,600 gallons and water and sewer fees of $0.50 per 750 gallons each); (2) treatment chemical savings would be $210 per month (based on a 25 percent reduction in existing treatment chemical costs); and (3) sludge disposal cost savings would be $50 per month (based on a 25 percent reduction in sludge volume generated each month). Total savings would be approximately $310 per month.

The use of automated rinse water flow controls will require significant capital investment. A pH/conductivity meter used to automatically turn rinse water on and off will cost approximately $700 to purchase and install. If these controls were purchased for all nine rinse tanks, the total cost would be $6,300. Savings would depend on the reduction in water usage that could be achieved. Since drag-out rates for process baths and operating parameters for the rinse systems were not available, estimates on saving that can be achieved by installing automated flow controls cannot be calculated. However, one printed circuit board manufacturer estimated that water use was reduced by 67 percent by installing flow control meters. For illustrative purposes, a more conservative estimate of 25 percent reduction in water use will be used. Therefore, the use of automated flow control meters could also save Sun Circuits $310 per month. At that savings rate, payback on investment would take 21 months.

Feasibility Analysis Phase

The recommended options were evaluated for their technical and economic feasibility by the consultants, who obtained cost and performance data from vendors where new equipment was recommended. The result of the technical and economic feasibility analyses was a list of feasible options, which became part of the assessment's final report. The next waste minimization assessment phase, Implementation, was left to the discretion of the printed circuit board manufacturer, Plant A.

The specific economic aspects of implementing each of the source reduction/resource recovery options were not separately documented by Plant A. Most of the source reduction options employed are essentially good operating practices, and hence did not require a large capital investment. However, the rework strategies and their evolution did require a large R&D expenditure. The implementation of these measures seemed to be guided more by the intuition and foresight of the plant personnel than by the calculated benefits that may have been indicated by a specific detailed economic evaluation.

RINSE WATER REDUCTION

Operating the rinse tanks as batch rinse systems or reducing the rate of water flow through the rinse tanks can

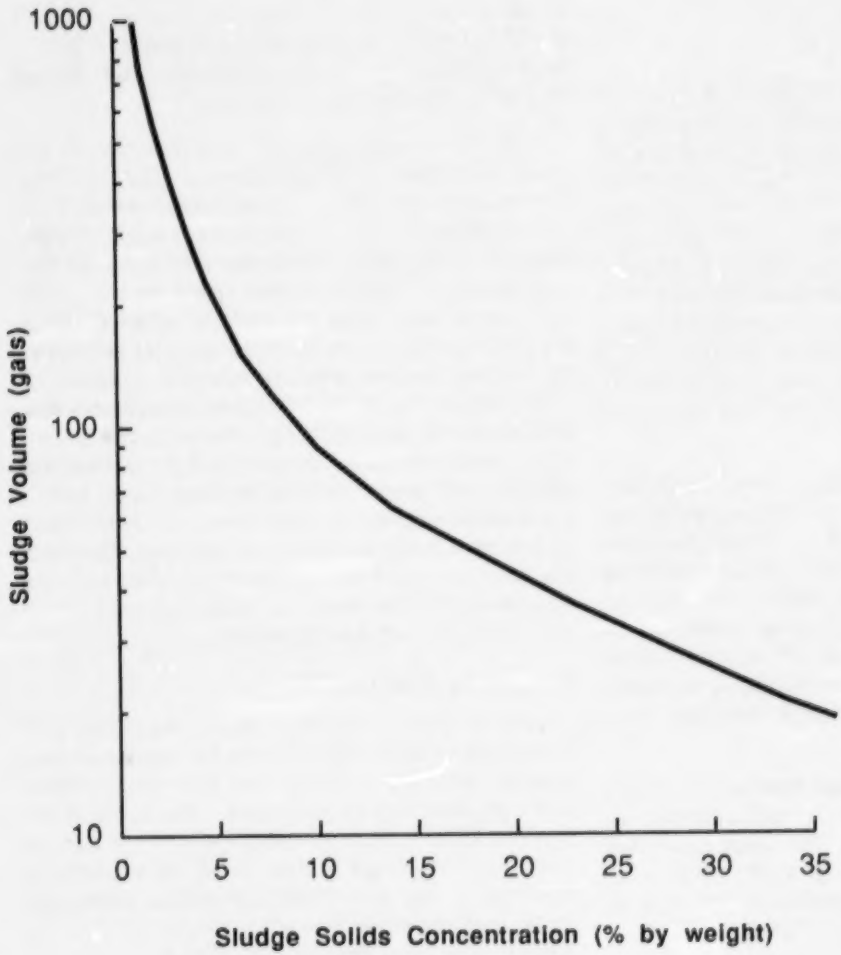

Figure A-2 - Sludge Volume Vs Sludge Solids Concentration

be implemented for minimal costs. To operate the rinse tanks as batch rinse systems, the plant would need additional labor to manually dump the rinse tanks. Flow restrictors for reducing the flow of water through rinse tanks would require only minor capital investments. The resulting savings in water usage, sewer fees, and treatment chemical costs would depend on the reduction in water use achieved.

Table A-5 indicates that water usage can be reduced by 6,920 gallons per day, or approximately 80 percent, if all the rinse tanks were operated as batch rinse systems. Assuming 20 work days per month, water usage could be reduced by 138,400 gallons each month. Since both water usage and sewer discharge fees are approximately $0.50 per 750 gallons, Plant A would save approximately $190 each month on water and sewer fees by reducing water usage by 138,400 gallons. As stated in Section 2.3, Plant A spends approximately $850 each month on treatment chemicals. Therefore, an 80 percent reduction in wastewater generation could reduce treatment chemical costs by as much as 80 percent. This would amount to a savings of $680 each month. Actual treatment chemical savings may be less because the wastewater will have a higher contaminant concentration and thus may require greater treatment chemical feed rates per volume of wastewater. Reductions in sludge volume will depend on the efficiency of the treatment system and the actual reductions in treatment chemical usage.

The use of various drag-out reduction techniques will increase the potential for reducing rinse water usage because less process chemicals will enter the rinse system. By installing a bar rail above each process tank for hanging workpiece racks, the plant could allow for greater drainage time before rinsing. This bar could be installed by Plant A personnel for a few hundred dollars if constructed out of 1 inch PVC piping. Other drag-out reduction techniques such as slowing workpiece rack removal rates and operating process baths at the lowest possible concentration can be implemented for little cost. Savings associated with drag-out minimization cannot be quantified until the techniques are implemented.

EQUIPMENT CLEANOUT

Plant A can reduce waste nitric acid generation by using a multiple tank cleaning line. The costs associated with setting up such a system include the cost of additional tanks and the installation labor costs. The costs for setting up a cascade cleaning line would be approximately $350 per tank. Labor costs of $55 an hour for 4 hours would be $220.

The savings associated with a multiple tank plating rack cleaning line include reduced costs for nitric acid purchases and waste acid handling. The consultants visited one plant that used five 15-gallon tanks as a multiple stage cleaning line. The plant generates 15 gallons of waste nitric acid every 6 months. If Plant A could reduce its waste nitric acid generation from 60 gallons to 15 gallons per 6 months, it would achieve a savings of $140 in nitric acid purchases and $90 in waste disposal costs each 6 months. This is based on nitric acid costing approximately $3.10 per gallon and waste disposal costs being approximately $2.00 per gallon.

MATERIAL RECYCLING

The auditors identified three waste materials for recycling: (1) photoresist stripper waste, (2) acidic rinse water effluent, and (3) copper sulfate crystals. Decanting or filtering spent stripper waste so it can be reused will require minor purchases to set up a decantation system or a filter system. Savings would include fewer fresh stripper purchases and lower stripper waste disposal costs. If decantation or filtration could be used to extend the process bath life from 2 weeks to 4 weeks, Plant A could reduce stripper purchases by 30 gallons each month. Once the stripper becomes too dilute for continued use, it can be filtered once more and used in the treatment system for pH adjustment. This could save Plant A $50 each month for disposal of stripper waste. A polymer sludge residue would still be generated, however.

To implement a system to reuse rinse water effluent from rinse tank 16 for feed water into rinse tank 14, Plant A would need to spend approximately $1,000. This includes $500 for contractor labor for 1 day and $500 for materials that include piping materials and a three-quarter horsepower pump, which would be adequate for a typical rinse system. Assuming that both rinse systems operate at the same flow rate, no storage tank capacity would be necessary.

Savings associated with recycling rinse water have been estimated based on Plant A's current water usage. Water and sewer fee savings would be approximately $13 each month based on a reduction in water usage of 500 gallons each day. Since wastewater generation would be reduced by 5 percent, treatment chemical usage could also be reduced by approximately 5 percent. A 5 percent reduction in the company's existing treatment chemical costs, which are $850 per month, would save Plant A $42 each month in treatment chemical purchases.

Copper sulfate crystals generated by Plant A could be recycled by adding them to the industrial waste sludge. There is no additional cost associated with mixing the crystals and the sludge since the crystals are also handled as hazardous waste if kept separate. Since the sludge is sent to a metal reclaimer, Plant A may receive a larger payment for reclaimed metals due to increased copper content in the sludge.

Table A-5. Rinse WaterWaste Generation

Operating as Flow-Through Tanks at a Rate of 16 gpm

Tank Number	Time Water is Running	Daily Flow Rate
2	96 minutes	1536 gallons
4	96 minutes	1536 gallons
7	96 minutes	1536 gallons
9	96 minutes	1536 gallons
10	96 minutes	1536 gallons
14	30 minutes	480 gallons
16	30 minutes	480 gallons
		8640 gallons

8640 gallons wastewater generated each day.

Operating as Batch Tanks Holding 30 Gallons of Rinse Water

Tank Number	Number of Batches Daily	Volume of Wastewater Generated Daily
2	12	360
4	12	360
6	12	360
8	12	360
10	12	360
14	2	60
16	2	60
		1720 gallons

1720 gallons generated each day.

WASTE SEGREGATION

The costs and savings associated with segregating chelated and nonchelated waste streams will depend on the design requirements of the segregation and the modifications to the treatment system that can be made once the materials are segregated. Assuming segregation will only entail installing a 500-gallon storage tank, pumps, gauges, and necessary piping, equipment costs would range between $2,000 and $4,000. Double containment would be more expensive. In addition, installation costs may be as high as 100 percent of equipment costs.

As discussed in Section 5.1, the ferrous sulfate used to treat the wastewater contributes approximately 34 percent of the total sludge volume. The ferrous sulfate also costs Plant A approximately $250 each month to purchase. Savings associated with segregating chelated waste streams and batch treating them will depend on the percentage of ferrous sulfate usage that can be eliminated through batch treatment of chelated waste streams. Since information on which process chemicals contain chelators was not available to the audit team, development of segregation alternatives and estimates for material and waste disposal cost savings could not be developed.

SLUDGE DEWATERING

Small filter press units designed to handle from 0.75 to 3.75 gallons of sludge per load cost between $2,800 and $4,900. Assuming that Plant A already has a source of compressed air, the company can install the unit itself. The unit can handle 7.5 to 37.5 gallons of sludge per 5-day work week. These units can increase solids content from 1 percent to approximately 35 percent. Plant A's current bag filter dewatering unit can achieve a sludge solids concentration of 11 percent. An increase in solids concentration from 11 percent to 35 percent will reduce sludge volume by approximately 75 percent. This could reduce the plant's sludge generation from approximately 200 gallons to about 50 gallons per month. Since Plant A estimates that sludge disposal costs approximately $1.00 per gallon, this sludge dewatering could save the company approximately $150 each month in disposal costs.

SUMMARY

The audit of Plant A was performed to identify opportunities for waste reduction. The following hazardous wastes are generated by Plant A each month:

- Industrial waste sludge- Approximately 200 gallons
- Photoresist stripper waste- Approximately 60 gallons
- Copper sulfate crystals- Undetermined
- Nitric acid waste- Approximately 10 gallons
- Reflow oil - Undetermined

The audit provided information that is useful to identify several waste reduction techniques that may be feasible for Plant A to implement. The following waste reduction opportunities were identified:

- Use process chemistries that can be recycled or treated when they are spent instead of chemistries that currently are containerized for off-site disposal.
- Use non-chelated process chemistries to replace chelated chemistries.
- Operate the rinse tanks as batch rinse systems.

- Reduce the flow rate used in the flow-through rinse tanks.
- Use flow restrictors and automated flow controls to reduce rinse water usage.
- Aggressively pursue drag-out reduction by developing operational procedures and training personnel to slowly remove workpiece racks and increase drainage time prior to rinsing.
- Install a multiple-stage electroplating rack cleaning line to reduce nitric acid waste generation.
- Reuse rinse water effluent from rinse systems following acidic baths as rinse water influent to rinse systems that follow alkaline cleaning baths.
- Mix copper sulfate crystals with industrial waste sludge for off-site metals reclamation.
- Segregate chelated waste streams from non-chelated waste streams and batch treat them.
- Dewater sludge using a mechanical filter press.

References

DHS. 1987. *Waste Audit Study - Printed Circuit Board Manufacturers*. June 1987. Prepared for California Department of Health Services, Alternative Technology Section (Sacramento, California) by Planning Research Corporation.

PLANT B WASTE MINIMIZATION ASSESSMENT

The waste minimization assessment of Plant B followed the same protocol used for Plant A, and included:

- Planning and organization
- Assessment phase
- Feasibility analysis phase

Implementation of selected waste minimization options was left to the discretion of Plant B.

Planning and Organization

Planning and organization of the assessment were a joint effort of the consulting firm and the PC board manufacturing plant's operations manager. As summarized in Figure 1, this phase of the assessment involved getting company management commitment to the project, setting goals for the assessment, and establishing a task force (the consultants working in cooperation with the plant operations manager) to conduct the assessment.

Assessment Phase: Process and Facility Data

The consultants worked with the plant operations manager to establish a data base of the facility's raw material needs, materials handling procedures, and operations processes. Block flow diagrams were drawn up to identify where materials are used and where waste is generated. Initial study of this information and discussions of waste stream concerns at the plant served as preliminary steps to the site inspection, during which additional process and waste handling information was obtained.

FACILITY DESCRIPTION

Plant B is a prototype circuit board manufacturer specializing in jobs involving limited production and fast turnaround. Manufacturing operations include drilling and routing, layering (for multilayer boards), photoresist printing, plating, etching, and stripping.

PROCESS DESCRIPTION

Figure B-1 is a floor plan of the plant's plating and etching process area. The numbers listed in the floor plan represent the identification number for each process bath and rinse tank. Tables B-1 and B-2 describe Plant B's rinsing operations and chemical process baths, respectively.

The plant presently uses seven dip tanks and two spray rinse tanks. All the dip rinse tanks are equipped with pH/conductivity meters that control the flow of water through the rinse tanks. The spray rinse tanks are all operated with foot pedals for turning on the water.

WASTE DESCRIPTION

Production activities that generate hazardous waste are the plating, etching, and stripping processes. The sources of waste from these activities are rinsing operations, spent process bath dumping, and industrial waste treatment, and equipment cleanout. This chapter describes the hazardous waste generating and handling activities performed at Plant B and describes the volume and characteristics of the hazardous wastes generated. Table B-3 lists Plant B's hazardous waste management characteristics.

Rinsing Operations

Rinsing operations associated with the chemical process lines are the major source of wastewater at Plant B. Wastewater generation fluctuates between 7,000 to 11,000 gallons per day. The rinse operations contribute to hazardous waste generation because waste rinse water carries away chemicals which are then removed by treatment at the industrial waste treatment plant. The sludge that is generated from this treatment is handled as a hazardous waste.

Spent Chemical Bath Dumping

When process chemical baths become too contaminated or diluted for use (spent), it is removed from the process tank. The spent chemical bath is then either containerized for reclamation by the manufacturer, containerized for off-site disposal, used as a neutralization chemical in the industrial waste treatment system, or dumped into the wastewater collection sump. A schedule for dumping each spent process bath was not available from Plant B, but plant personnel indicated that the frequency varies. A bath is changed when personnel recognize that the effectiveness of the bath is no longer adequate.

Only two of the spent bath handling methods contribute to the amount of hazardous waste generated at the plant. These methods include containerizing spent baths for off-site disposal and dumping of spent chemical baths into the wastewater sump. The only process chemical baths containerized for disposal are the photoresist strippers and the reflow oil. Approximately 25 gallons of waste reflow oil is generated every 2 months. The volume of stripper waste generated was not estimated by Plant B. Chemical baths treated at the industrial waste treatment facility are transferred to one of the two wastewater sumps where the chemicals are neutralized. The waste is then fed into the industrial waste treatment system.

Copper sulfate crystals are also generated when some of the process baths are taken off-line. The crystals form in the process bath as the copper concentration increases. Before the process baths are dumped into the wastewater sump, the crystals are containerized as a solid waste since

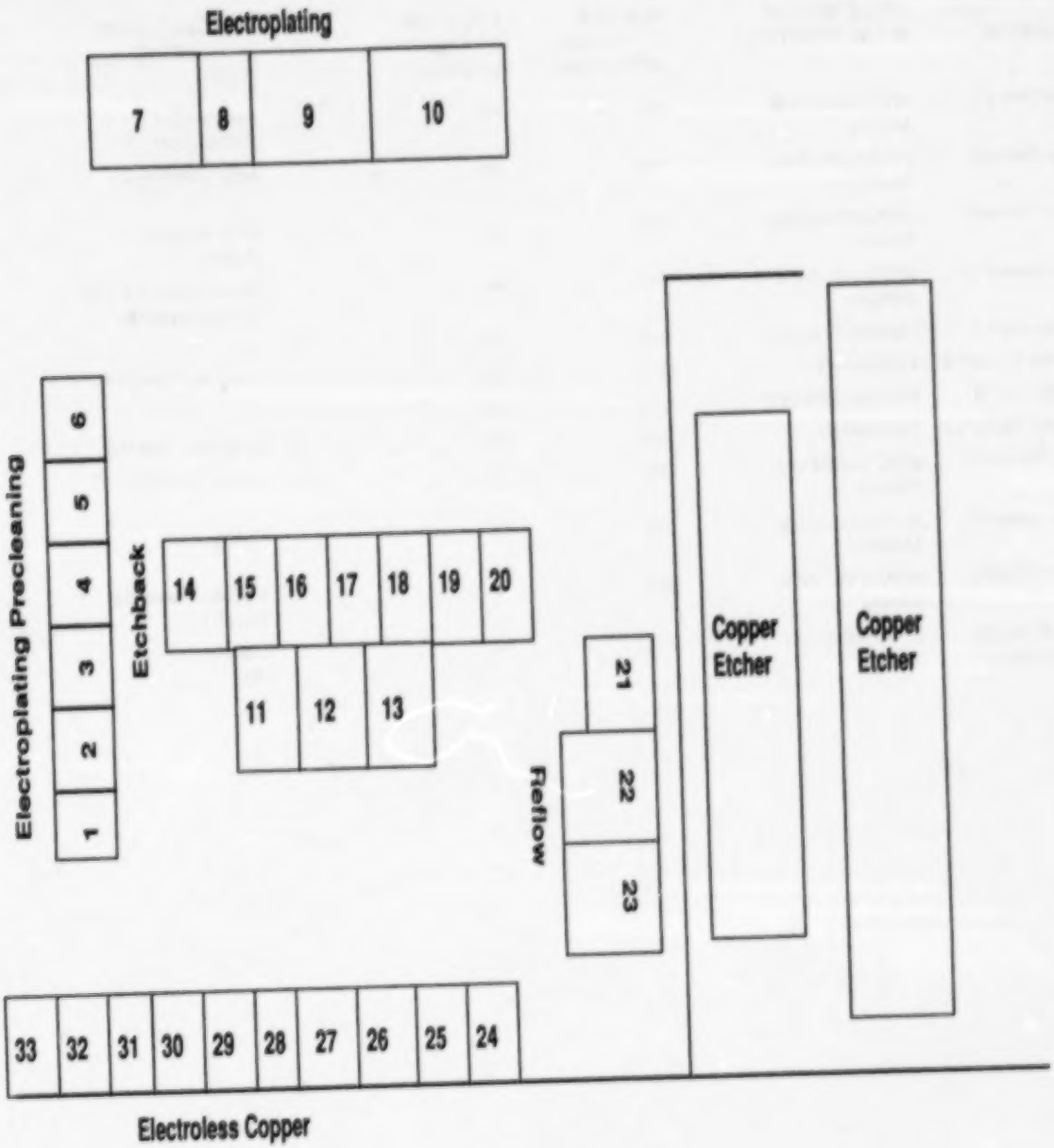

Figure B-1 Plant B's Etching and Plating Facility

Table B-1. Rinse System Information

RINSE TANK/ NUMBER	RINSE WATER FLOW CONTROLS	NUMBER OF TANKS IN SYSTEM	COUNTER CURRENT SYSTEM	PROCESS BATH PRECEDING RINSE
Dip Rinse/1	pH/Conductivity Meters	one	no	Ammonium Bifluoride/2
Dip Rinse/3	pH/Conductivity Meters	one	no	MBL Cleaner/4
Dip Rinse/5	pH/Conductivity Meters	one	no	98% Sulfuric Acid/6
Dip Rinse/12	pH/Conductivity Meters	one	no	Black Oxide/11 and Tin Immerse/13
Drag-out/14	Manual Dumping	one	NA	---
Spray Rinse/15	Footpedals	one	NA	Drag-out Tank/14
Drag-out/18	Manual Dumping	one	NA	---
Spray Rinse/19	Footpedals	one	NA	Drag-out Tank/18
Dip Rinse/26	pH/Conductivity Meters	two	no	Rinse Tank/27
Dip Rinse/27	pH/Conductivity Meters	two	no	Catalyst
Dip Rinse/30	pH/Conductivity Meters	one	no	Sulfuric-Peroxide Etch/31
Dip Rinse/32 Conditioner	pH/Conductivity Meters	one	no	Cleaner- /33

Table B-2. Process Bath Information

PROCESS BATH/ NUMBER	PROCESS BATH VOLUME (gallons)	METHOD OF DISPOSAL
Ammonium Bifluoride/2	50 gal.	To wastewater treatment facility
MBL Cleaner/4	50 gal.	To wastewater treatment facility
98% Sulfuric Acid/6	20 gal.	To wastewater treatment facility
Tin-Lead Bath/7	400 gal.	---
Fluorboric Acid/8	50 gal.	To wastewater treatment facility
Copper Sulfate/9	400 gal.	---
Copper Sulfate/10	400 gal.	---
Black Oxide/11	50 gal.	To wastewater treatment facility
Tin Immerse/13	50 gal.	To wastewater treatment facility
10% Sulfuric Acid/16	50 gal.	To wastewater treatment facility
Sulfuric/Peroxide Etch/17	50 gal.	To wastewater treatment facility
Soap Cleaner/20	50 gal.	To wastewater treatment facility
Reflow Flux/21	2 gal.	Off-site disposal
Reflow Oil/22	15 gal.	Off-site disposal
Reflow Oil/23	15 gal.	Off-site disposal
Electroless Copper/24	50 gal.	To wastewater treatment facility
Accelerator/25	50 gal.	To wastewater treatment facility
Catalyst/28	50 gal.	To wastewater treatment facility
Catalyst Prep/29	50 gal.	To wastewater treatment facility
Sulfuric-Peroxide Etch/31	50 gal.	To wastewater treatment facility
Cleaner-Conditioner/33	50 gal.	To wastewater treatment facility

Table B-3. HazardousWaste Data

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
Industrial Treatment Sludge	300 gal.	Off-site metal reclamation	$40/55 gal. drum	$240
Photoresist Stripper	---	Off-site disposal	$100/55 gal. drum	---
Nitric Acid	30 gal.	Off-site disposal	$100/55 gal.$50 drum	
Reflow Oil	150 gal.	Off-site disposal	$100/55 gal. drum	$300

they cannot be fed into the treatment system. The crystals are mixed with the plant's industrial waste sludge, which is transported offsite for metal reclamation.

Industrial Wastewater Treatment

Plant B's industrial waste treatment facility treats all wastewater prior to discharge to the San Jose/Santa Clara Water Pollution Control Plant. Plant B's treatment facility removes metals and adjusts the pH of the wastewater to meet the maximum allowable concentration of metals in the discharged effluent, as set by the San Jose/Santa Clara Water Pollution Control Plant. These maximum concentrations are as follows:

Chromium	1.0 mg/L
Copper	2.7 mg/L
Cyanide	1.0 mg/L
Lead	0.4 mg/L
Nickel	2.6 mg/L
Silver	0.7 mg/L
Zinc	2.6 mg/L

The treatment process includes neutralization, metals precipitation, filtration, and sludge dewatering. The treatment plant is located outside the main building in a curbed area. The metal hydroxide sludge generated by this treatment process is a hazardous waste. The treatment system generates approximately 25 gallons of sludge every month. The sludge dewatering unit produces a sludge that has a solids concentration of 35 percent. The sludge is transported offsite to World Resources of Phoenix, Arizona for metal reclamation. World Resources analyzes a sample from each load of sludge it receives. The analytical data provided by World Resources for the sludge generated by Plant B are as follows:

Percent solids	35%
Metal content in pounds per dry ton	
Copper	250
Nickel	11
Tin	59
Iron	12
Lead	22
Zinc	8

Equipment Cleanout

The primary source of hazardous waste associated with equipment cleanout is the cleaning of electroplating racks. Plant B uses nitric acid in a five tank cleaning line to clean electroplating racks. Each tank holds approximately 15 gallons of nitric acid. The acid in the first tank requires changing approximately every 6 months. When the nitric acid in the first tank is dumped, the remaining four tanks all move up one step in the cleaning line. The empty tank is filled with fresh nitric acid and is used as the last tank in the cleaning line. The waste nitric acid has too low a pH and too high a copper content to be treated in the industrial waste treatment system.

Other cleaning activities, such as floor washing and chemical bath tank rinsing, generate waste streams that discharge into the wastewater collection sump. According to Plant B personnel, these waste streams make up a small portion of the chemicals that enter the treatment system.

Assessment Phase: Option Generation

After the site inspection, the plant operations manager and the consultant team reviewed the raw material, process, and waste stream information and developed a number of waste minimization options for consideration. These options fall into the categories of source reduction techniques and recycling and resource recovery techniques.

SOURCE REDUCTION MEASURES

Plant B appears to have effectively implemented several technologies to reduce the volume of hazardous waste it generates. Water conservation techniques, such as rinse water flow control meters and pressure activated spray rinse tanks, are presently used at the plant. The industrial waste treatment system appears to effectively treat wastewater without producing excessive volumes of sludge. Plant B personnel stated that their effluent consistently meets the discharge requirements set by the San Jose/Santa Clara Water Pollution Control Plant. Also, the volume of sludge generated by the wastewater treatment system is lower than the volume generated at other manufacturing plants of comparable size and wastewater generation rates. For example, Plant B generates approximately 50 gallons of sludge every 2 months compared to another plant with a comparable wastewater generation rate that generates approximately 200 gallons of sludge every month. Nevertheless, several additional opportunities for waste reduction may be available to Plant B that can further reduce its hazardous waste generation. This section describes these opportunities.

MATERIAL SUBSTITUTION

Plant B may be able to reduce the volume of spent process chemicals and cleaning solutions containerized for off-site disposal by substituting materials. Two materials that Plant B handles as hazardous waste are spent reflow oil

and spent nitric acid. Several reflow oil products are available that, when spent, either can be returned to the supplier for recycling or can be treated by the facility prior to discharge to the Publicly Owned Treatment Works. Plant B could eliminate a hazardous waste stream by replacing its present reflow oil with a recyclable or treatable reflow oil.

Nitric acid waste, which is generated from the cleaning of electroplating racks, can also be eliminated by using an alternative cleaning solution. One chemical supplier offers an electroplating rack cleaning solution that can be regenerated. The metal stripped off of racks during the cleaning process can be plated out in a tank equipped with a cathode and an anode. The metal stripped from the racks is plated onto the cathode and forms a metallic sludge that settles to the bottom of the cleaning tank. Once the solution becomes spent, it can be treated in the plant's industrial treatment system instead of being containerized for off-site disposal. Plant B should consult with chemical suppliers to identify alternative materials that can be recycled or treated and that will meet its specific operating requirements.

DRAG-OUT LOSS REDUCTION

Discussions with Plant B personnel indicated that little attention is placed on drag-out reduction. Although the plant does not generate excessive amounts of sludge, further reductions in sludge volume may be obtained by using drag-out reduction technologies. Reductions in drag-out loss should also have a direct impact on water usage. Since water flow through the rinse systems are controlled by pH/conductivity controls, drag-out reduction will decrease the frequency of rinse water flow through the rinse tanks. Plant B may be able to reduce drag-out by instituting operational modifications and training personnel in drag-out reduction techniques. Drag-out reduction techniques include slowing the workpiece rack withdrawal rates and increasing drainage time prior to rinsing. Other drag-out reduction methods include operating process baths at the lowest allowable concentration and using heated process baths when possible.

The faster an item is removed from the process bath, the thicker the film on the workpiece surface and the greater the drag-out volume will be. The effect is so significant that most of the time allowed for withdrawal and drainage of a rack should be used for withdrawal only. Plant B management should emphasize to process line operators that workpieces should be withdrawn slowly. An optimal removal rate can be determined by removing loaded workpiece racks from process baths at different rates and allowing the rack to drain into a catch basin. Drag-out volume can then be measured volumetrically.

Workpiece drainage also depends on the operator. The time allowed for drainage can be inadequate if the operator is rushed to remove the workpiece rack from the process bath and place it in the rinse tank. However, installation of a bar or rail above the process tank may help ensure that adequate drainage time is provided prior to rinsing. Plant B has expressed concern that increasing workpiece rack removal and drainage time will allow for chemical oxidation on the board. Plant B should identify the processes that are not highly susceptible to oxidation and emphasize drag-out minimization techniques to personnel operating those processes.

RINSE WATER RECYCLING

Plant B may be able to recycle its rinse water by further treating effluent from the industrial waste treatment plant. This additional treatment may only require activated carbon treatment to remove trace organics from the water. Plant B should assess the need for other levels of treatment, such as ion-exchange or other technologies, based on the quality of the treated effluent. This recycled water would contain less natural contaminants, such as phosphates and carbonates, than tap water, which is presently used. Since these natural contaminants contribute to sludge volume because they precipitate during treatment, the use of recycled rinse water can reduce hazardous waste sludge generation and significantly reduce water usage and sewer discharge fees.

Feasibility Analysis Phase

After discussions with Plant B personnel, some of the options discussed in the previous section were selected for investigation of their technical and economic feasibility. The economic analysis was based on the raw material and waste disposal costs provided by the facility personnel and on economic and technical information provided by equipment manufacturers. The measures evaluated in this section include: material substitution, drag-out loss reduction and rinse water recycling.

MATERIAL SUBSTITUTION

The benefits associated with using recyclable and/or treatable process chemistries will depend on the costs of substitute materials compared with the costs of materials presently used. Also, additional process bath maintenance requirements and treatment costs need to be identified. These costs will depend on the type of substitute material chosen by Plant B.

Savings will include reduced waste disposal costs and material usage costs if the substitute material can be recycled. Plant B generates 150 gallons of waste reflow oil and 30 gallons of waste nitric acid annually. Since waste disposal costs for the waste reflow oil and waste nitric acid are both $100 per 55-gallon drum, which is the average cost

for disposing of various liquid hazardous wastes according to PC board manufacturers, waste disposal cost savings would be approximately $300 per year for spent reflow oil and $50 per year for nitric acid waste. Actual savings associated with using recyclable reflow oil and nitric acid will depend on the difference in the cost of the substitute materials.

DRAG-OUT LOSS REDUCTION

Several drag-out minimization techniques can be implemented at Plant B for minimal costs. The use of a bar rail above each process tank for hanging workpiece racks will allow for greater drainage time before rinsing. This could be installed by Plant B's personnel for a few hundred dollars if constructed of 1 inch PVC piping. Other drag-out reduction techniques, such as slowing workpiece rack removal rates and operating process baths at the lowest possible concentration, can also be implemented for little cost. Developing a training program and emphasizing drag-out minimization will require time from management and operations personnel. Since information on drag-out rates and workpiece rack removal and drainage times were not available from Plant B, savings associated with drag-out minimization cannot be quantified prior to implementation.

RINSE WATER RECYCLING

Considerable capital investment may be needed to recycle wastewater for reuse in production. The costs associated with recycling treated wastewater effluent will depend on the level of additional treatment necessary to return the effluent back into the production processes. Other plants that are considering rinse water recycling have indicated that their primary concern is to remove organics from the treated effluent before reusing the water. An activated carbon system to treat the effluent can be used to remove organics from the water. If various anions and/or cations in the effluent must also be removed, treatment technologies such as reverse osmosis or ion-exchange may be required.

Information describing the rinse system operating parameters and the water quality or Plant B's treated effluent were not obtained during the audit. Therefore, treatment requirements for returning treated effluent to the rinse systems could not be developed. Plant B should investigate the potential for recycling rinse water by characterizing its rinse water effluent, determining the water quality needs for reusing treated effluent, and identifying potential technologies that can be used to treat the effluent for reuse.

The primary savings associated with recycling rinse water is lower water purchase and sewer discharge fees. Plant B generates approximately 7,000 to 11,000 gallons of wastewater each day. For an average daily water usage of 9,000 gallons, and assuming that 90 percent of the water can be recycled, Plant B could reuse approximately 8,000 gallons of water each day. Since water and sewer fees are both approximately $0.50 per 750 gallons, Plant B could save approximately $10 each day in water and sewer costs.

SUMMARY

The audit of the Plant B was performed to identify opportunities for waste reduction. The following hazardous wastes are generated by Plant B annually:

Industrial waste sludge- Approximately 300 gallons

Photoresist stripper waste- Undetermined

Copper sulfate crystals- Undetermined

Nitric acid waste- Approximately 30 gallons

Reflow oil- Approximately 150 gallons

The audit was used to identify several waste reduction techniques that may be feasible for Plant B to implement. The following waste reduction opportunities were identified:

- Use alternative reflow oil and electroplating rack stripper materials that can be recycled or treated when they are spent instead of chemistries that currently are containerized for off-site disposal.
- Aggressively pursue drag-out reduction by developing operational procedures and training personnel to slowly remove workpiece racks and increase drainage time prior to rinsing.
- Recycle treated effluent for reuse in the production process.

PLANT C WASTE MINIMIZATION ASSESSMENT

The waste minimization assessment of Plant C followed the same protocol used for Plant A, and included:

- Planning and organization
- Assessment phase
- Feasibility analysis phase

Implementation of selected waste minimization options was left to the discretion of Plant C.

Planning and Organization

Planning and organization of the assessment were a joint effort of the consulting firm and the paint manufacturing plant's operations manager. As summarized in Figure 1, this phase of the assessment involved getting company management commitment to the project, setting goals for the assessment, and establishing a task force (the consultants working in cooperation with the plant operations manager) to conduct the assessment.

Assessment Phase: Process and Facility Data

The consultants worked with the plant operations manager to establish a data base of the facility's raw material needs, materials handling procedures, and operations processes. Block flow diagrams were drawn up to identify where materials are used and were waste is generated. Initial study of this information and discussions of waste stream concerns at the plant served as preliminary steps to the site inspection, during which additional process and waste handling information was obtained.

FACILITY DESCRIPTION

Plant C is a prototype circuit board manufacturer specializing in jobs involving limited production and fast turnaround. Manufacturing operations include drilling and routing, layering (for multilayer boards), plating, and etching.

PROCESS DESCRIPTION

Figure C-1 is a floor plan of the plant's plating and etching process area. The numbers listed on the floor plan represent the identification number for each process bath and rinse tank. Tables C-1 and C-2 describe Plant C's rinsing operations and chemical process baths, respectively.

WASTE DESCRIPTION

Production activities that generate hazardous waste are the plating and etching processes. The sources of waste from these activities are rinsing operations, spent process bath dumping, industrial waste treatment, and equipment cleanout. This chapter of the report describes the hazardous waste generating and handling activities performed at Plant C and describes the volume and characteristics of the hazardous wastes generated. Table C-3 lists Plant C's hazardous waste management characteristics.

Rinsing Operations

Rinsing operations associated with the chemical process lines are the major source of wastewater at Plant C. Facility personnel estimate that approximately 3,000 gallons of wastewater are generated each day. The rinse operations contribute to hazardous waste generation because waste rinse water carries away chemicals which are then removed by treatment at the industrial waste treatment plant. The sludge waste that is generated from this treatment is then handled as a hazardous waste.

The plant uses 11 dip rinse tanks that discharge to the industrial waste treatment plant and two drag-out tanks that are periodically dumped manually into the wastewater sump. All of the rinse tanks are plumbed directly to the wastewater treatment system via a collection sump. Discussions with facility personnel indicate that water flows through the dip rinse tanks only when the process line associated with the tank is in operation. Water flow for each rinse tank is turned on and off manually by production personnel. Plant C installed flow restrictors in each rinse system's water inflow line to control water usage.

Four of the rinsing operations are double rinse tank system (tanks 5 and 6, tanks 15 and 16, tanks 21 and 22, and tanks 30 and 31). These four rinse systems, however, are not plumbed in series as counter-current rinse systems. Instead, each tank has a separate rinse water influent and effluent water line.

Spent Chemical Bath Dumping

When process chemical baths become too contaminated or diluted for use (spent), they are removed from the process tank. The spent chemical bath is then either containerized for reclamation by the manufacturer, containerized for off-site disposal, or dumped into the wastewater collection sump. A schedule for dumping each spent process bath was not available from Plant C, but plant personnel indicated that the frequency varies. A bath is changed when personnel recognize that the effectiveness of the bath is no longer adequate.

Only two of the spent bath handling methods contribute to the amount of hazardous waste generated at the plant. These methods are containerizing waste for off-site disposal and dumping of spent chemical bath into the wastewater sump. The process chemical bath containerized for disposal is the reflow oil. The plant generates approximately 20 gallons of waste reflow oil each month.

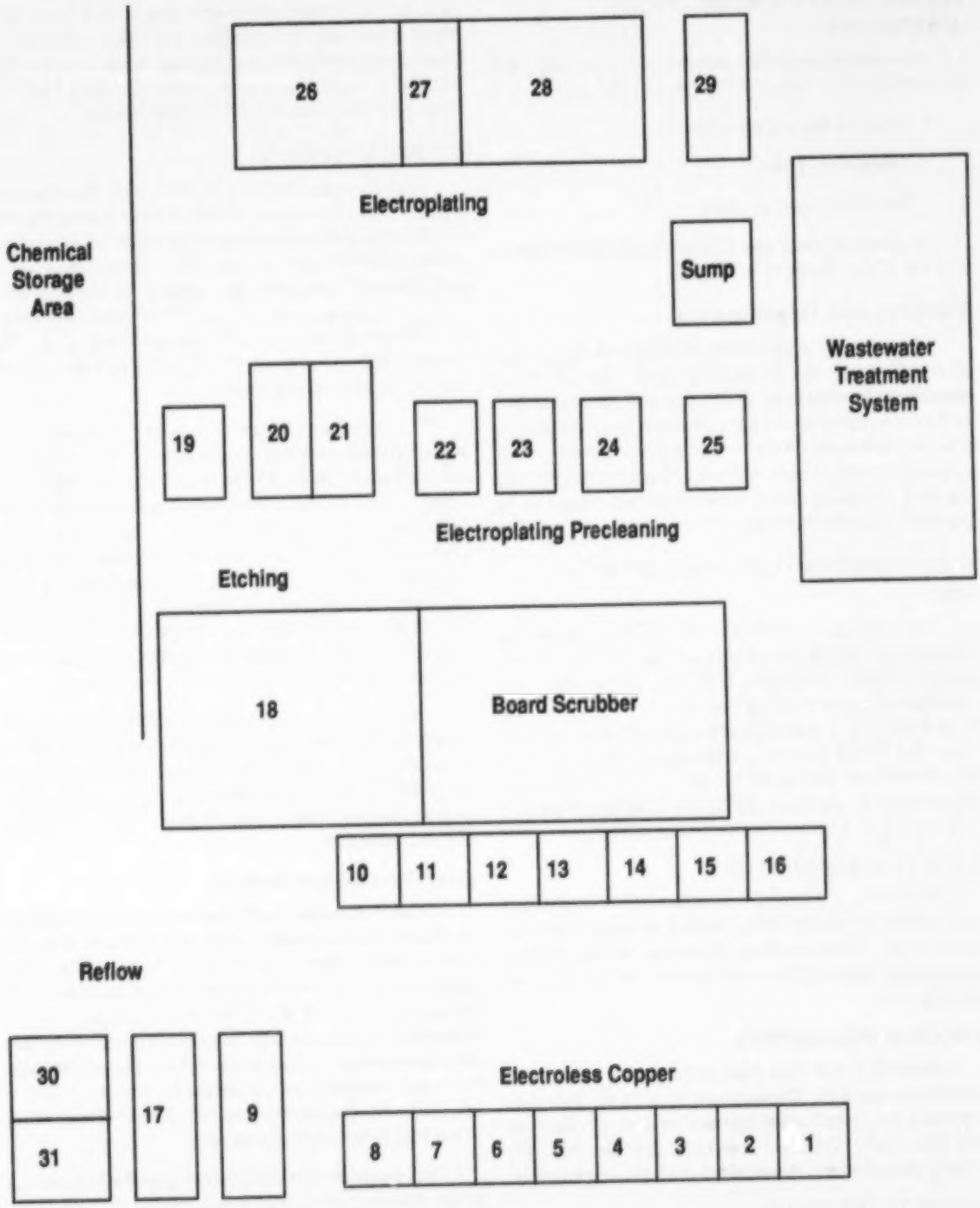

Figure C-1. Plant C's Etching And Plating Facility

Table C-1. Rinse System Information

RINSE SYSTEM NUMBER	NUMBER OF TANKS	COUNTER CURRENT SYSTEM	PROCESS BATH PRECEDING RINSE SYSTEM
Dip Rinse/3	One	No	Soap Cleaner/2
Dip Rinse/5	Two	No	Peroxide Etchback/4
Dip Rinse/6	Two	No	Dip Rinse Tank/5
Dip Rinse/9	One	No	Catalyst/8
Dip Rinse/12	One	No	Electroless Copper/11
Dip Rinse/15	Two	No	Tin/Lead Stripper/14
Dip Rinse/16	Two	No	Dip Rinse Tank/5
Dip Rinse/20	Two	No	Micro Etch Cleaner/19
Dip Rinse/21	Two	No	Dip Rinse Tank/20
Drag-out/27	One	No	Copper Sulfate/26
Drag-out/29	One	No	Tin-Lead/28
Dip Rinse/30	Two	No	Reflow Oil/17
Dip Rinse/31	Two	No	Reflow Oil/17

Table C-2. Process Bath Information

PROCESS BATH/ IDENTIFICATION NUMBER	PROCESS BATH VOLUME IN TANK	METHOD OF DISPOSAL
Nickel Sulfate/1	30 gal.	Discharge to treatment facility
Soap Cleaner/2	30 gal.	Discharge to treatment facility
Peroxide Etchback/4	30 gal.	Discharge to treatment facility
10% Hydrochloric Acid/7	30 gal.	Discharge to treatment facility
Catalyst/8	30 gal.	Replenished, not disposed
Accelerator/10	30 gal.	Discharge to treatment facility
Electroless Copper/11	30 gal.	Replenished, not disposed
10% Hydrochloric Acid/13	30 gal.	Discharged to treatment facility
Tin/Lead Stripper/14	30 gal.	Discharged to treatment facility
Reflow Oil/17	20 gal.	Off-site disposal
Ammonium Etchant/18		Recycled by manufacturer
Micro Etch Cleaner/19	50 gal.	Discharged to treatment facility
Sulfuric Acid/22	50 gal.	Discharged to treatment facility
Fluorboric Acid/23	50 gal.	Discharged to treatment facility
Solder Bright/24	50 gal.	Discharged to treatment facility
Nitric Acid/25	50 gal.	Off-site disposal
Copper Sulfate/26	400 gal.	Replenished, not disposed
Tin-Lead/28	400 gal.	Replenished, not disposed

Table C-3. Hazardous Waste Data

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
Spent Ion Exchange Resin	1200 gal.	Transported off-site for disposal	$2.00/gal.	$2,400
Nitric Acid	480 gal.	Transported off-site for disposal	$2.00/gal.	$ 960
Reflow Oil	240 gal	Transported off-site for disposal	$2.00/gal.	$ 480
Copper Sulfate Crystals	Undetermined	Transported off-site for disposal	$2.00/gal.	---

Other process baths are discharged to the treatment plant when they are spent (except for the etchant, which is sent back to the supplier for reclaim). Copper sulfate crystals are also generated when some of the process baths, such as the peroxide/sulfuric etch, are taken off-line. The crystals form in the process bath as the copper content increases. Before the process baths are dumped into the wastewater sump, the crystals are removed and containerized as a solid hazardous waste since they cannot be fed into the treatment system. Plant C did not estimate the volume of copper sulfate crystals generated each month.

Industrial Wastewater Treatment

Plant C's industrial waste treatment facility treats all wastewater prior to discharge to the San Jose/Santa Clara Water Pollution Control Plant. Plant C's treatment facility removes metals and adjusts the pH of the wastewater to meet the maximum allowable concentration of metals in the discharged effluent, as set by the San Jose/Santa Clara Water Pollution Control Plant. These maximum concentrations are as follows:

Chromium	1.0 mg/L
Copper	2.7 mg/L
Cyanide	1.0 mg/L
Lead	0.4 mg/L
Nickel	2.6 mg/L
Silver	0.7 mg/L
Zinc	2.6 mg/L

The treatment process includes filtration, ion-exchange, and neutralization. The ion-exchange (IE) system was recently installed to replace Plant C's conventional precipitation/clarifier treatment system. The Ion Exchange unit has a treatment capacity of 12 to 14 gallons per minute. The Ion Exchange unit produces less hazardous waste than the old treatment system. The hazardous waste generated by the Ion Exchange treatment process is spent ion-exchange resin. Approximately 100 gallons of waste resin are generated each month, compared to approximately 300 gallons of sludge generated by the old treatment system.

Equipment Cleanout

The primary source of hazardous waste associated with equipment cleanout is the cleaning of the copper etching tank, the tanks used in the electroplating line, and the electroplating racks. This equipment is cleaned by using nitric acid. Plant C estimates that approximately 40 gallons of waste nitric acid are generated each month. The waste nitric acid has too low of a pH and too high of a copper content to be discharged to the treatment facility.

The nitric acid solution is stored in a single 50-gallon tank where electroplating racks can be immersed in the solution for cleaning. The nitric acid is used to strip the copper, tin, and lead from the equipment. When the acid loses its ability to effectively oxidize the metal, it is containerized for disposal. Electroplating rack cleaning is the greatest source of waste nitric acid.

Assessment Phase: Option Generation

After the site inspection, the plant operations manager and the consultant team reviewed the raw material, process, and waste stream information and developed a number of waste minimization options for consideration. These

options fall into the categories of source reduction techniques and recycling and resource recovery techniques.

SOURCE REDUCTION MEASURES

Plant C appears to have effectively implemented several technologies to reduce the volume of hazardous waste it generates. Water conservation techniques such as rinse water flow restrictors are presently used at Plant C, the plant's water use appears to be significantly lower than that of other plants of comparable size and production. For example, two other plants visited by the consultant generate approximately 10,000 gallons of wastewater each day compared to 3,000 gallons generated by Plant C each day. The ion exchange treatment system effectively treats wastewater without producing a hazardous waste sludge. This new treatment system produces approximately 100 gallons of spent ion exchange resin each month, with no sludge generated; the old treatment facility produced approximately 300 gallons of sludge each month. Nevertheless, several additional opportunities for waste reduction may be available to Plant C to further reduce its hazardous waste generation. This section describes these opportunities.

Material Substitution

Plant C may be able to reduce the volume of spent process chemicals and cleaning solutions containerized for off-site disposal by substituting materials. Two materials that Plant C handles as hazardous waste are spent reflow oil and spent nitric acid. Several reflow oil products are available that, when spent, either can be returned to the supplier for recycling or can be treated by the facility prior to discharge to the Publicly Owned Treatment Works. Plant C could eliminate a hazardous waste stream by replacing its present reflow oil with a recyclable or treatable reflow oil.

Nitric acid waste, which is generated from equipment cleanout, can also be eliminated by using an alternative cleaning solution. One chemical supplier offers an electroplating rack cleaning solution that can be regenerated. The metal stripped off of racks during the cleaning process can be plated out in a tank equipped with a cathode and an anode. In this method, metal stripped from the racks is plated onto the cathode and forms a metallic sludge that settles to the bottom of the cleaning tank. Once the solution becomes spent, it can be treated in the plant's industrial treatment system instead of being containerized for off-site disposal. Plant C should consult with chemical suppliers to identify alternative materials that can be recycled or treated and that will meet its specific operating requirements.

RINSE WATER REDUCTION

Plant C can reduce rinse water usage, as well as reduce the quantity of hazardous chemicals entering the waste stream, by converting several of its double tank rinse systems into two-stage, closed circuit counter-current rinse systems. By reducing water usage and quantity of chemical wastes, the load on the treatment system will be reduced and the longevity of the ion exchange resin can be increased. The plant currently uses four double tank rinse systems (tanks 5 and 6, tanks 15 and 16, tanks 20 and 21, and tanks 30 and 31; see Figure C1). Each tank, however, is plumbed separately. If the two tanks associated with each of the four rinse systems were plumbed in series as counter-current rinse systems, the plant could significantly reduce its rinse water use. Figure C2 illustrates the set-up for a two stage counter-current rinse system.

Plant C did not provide data on the flow rate used for each rinse tank. Therefore, calculations on actual water use savings cannot be presented. However, the following example illustrates how a counter-current rinse system can reduce water use compared with the present rinse system used at the plant. A facility operates a two stage rinse system with: (1) each tank having a separate water inflow line; (2) a water flow rate of 10 gallons per minute; and (3) the rinse water for the system turned on a total of 120 minutes per day. The total water usage for this system would be 2,400 gallons per day. The following equation can be used to illustrate how a two stage counter-current system could reduce rinse water usage at the facility:

$$Q = [(Cp/Cr)1/n + 1/n]D$$

Q = rinse tank flow rate

D = drag-out rate

Cp = chemical concentration on process solution

Cr = allowable chemical concentration in rinse solution

n = number of rinse tanks in series

Several assumptions must be made to use this equation. These are as follows:

- The concentration of chemicals in the rinse solution cannot exceed 1/1000 of the concentration of chemicals in the process bath. This value is a common parameter used in the electroplating industry for rinse water contaminant concentration.

- The drag-out rate of chemicals used for manufacturing printed circuit boards is approximately 15 ml/ft2 of board. This value is a standard approximation used for estimating drag-out created by a printed circuit board.
- An average workpiece rack holds approximately 2.5 ft3 of boards (example: 30 4-inch by 3-inch boards).

The drag-out rate for each workpiece rack is:

15 ml x 2.5 ft3 = 37.5 ml.

Converted to gallons, drag-out equals 0.01 gallon.

By substituting the values into the equation:

[(1000)1/2 + 1/2] 0.01 gallons/minute = 0.32 gallon/minute.

Therefore, if the facility converted its existing rinse system into a two-stage closed circuit counter-current rinse system, it could reduce the flow rate from 10 gallons per minute through each tank to 0.32 gallon per minute through both tanks. This would in theory reduce the daily water usage from 2,400 gallons to 38 gallons and would significantly reduce the quantity of hazardous chemicals entering the shop's treatment system. The actual volume of rinse water reduction that can be achieved by Plant C depends on the drag-out rate from the plant's process baths and the rinse system parameters for the four double rinse tank systems.

DRAG-OUT LOSS REDUCTION

Discussions with Plant C personnel indicated that little attention is placed on drag-out reduction. The plant may be able to generate less spent ion-exchange resin by using drag-out reduction technologies. Reductions in drag-out loss should also have a direct impact on water usage. Since water flow through the rinse systems are controlled by pH/conductivity controls, drag-out reduction will decrease the frequency of rinse water flow through the rinse tanks. Plant C may be able to reduce drag-out by instituting operational modifications and training personnel in drag-out reduction techniques. Drag-out reduction techniques include slowing workpiece rack withdrawal rates and increasing drainage time prior to rinsing. Other drag-out reduction methods include operating process baths at the lowest allowable concentration and using heated process baths when possible.

The faster an item is removed from the process bath, the thicker the film on the workpiece surface and the greater the drag-out volume will be. The effect is so significant that most of the time allowed for withdrawal and drainage of a rack should be used for withdrawal only. Plant C management should emphasize to process line operators that workpieces should be withdrawn slowly. An optimal removal rate can be determined by removing loaded workpiece racks from process baths at different rates and allowing the racks to drain into a catch basin. Drag-out volume can then be measured volumetrically.

Workpiece drainage also depends on the operator. The time allowed for drainage can be inadequate if the operator is rushed to remove the workpiece rack from the process bath and place it in the rinse tank. However, installation of a bar or rail above the process tank may help ensure that adequate drainage time is provided prior to rinsing. Other printed circuit board manufacturers have expressed concern that increasing workpiece rack removal and drainage time will allow for chemical oxidation on the board. Plant C should identify the processes that are not highly susceptible to oxidation and emphasize drag-out minimization techniques to personnel operating those processes.

EQUIPMENT CLEANOUT

Plant C generates approximately 40 gallons of waste nitric acid every month from equipment cleanout. Plant C may be able to reduce the volume of nitric acid generated by modifying the existing cleaning methods.

One method for reducing the volume of waste nitric acid produced is to setup a workpiece rack cleaning line with several small tanks of nitric acid. The cleaning line is then used like a multi-stage rinse system. The first tank contains the most contaminated nitric acid solution, and the final tank in the cleaning line contains the freshest nitric acid. When the first tank no longer performs adequate initial cleaning, it is containerized for disposal (or used as initial cleaning solution for tank cleanout). Then the second tank in the cleaning line becomes the first. The empty tank is then filled with fresh nitric acid and it becomes the last tank in the cleaning line.

The use of a multi-stage rinse system can provide significant reductions in waste cleaning solution generation. One printed circuit board manufacturing plant uses a five-stage multiple tank cleaning line and only generates approximately 15 gallons of waste nitric acid each 6 months.

RINSE WATER RECYCLING

Plant C may be able to recycle its rinse water by further treating effluent from the industrial waste treatment plant. This additional treatment may only require activated carbon treatment to remove trace organics from the water. This recycled water would contain less natural contaminants, such as phosphates and carbonates, than the tap water that is presently used. Since these natural contaminants

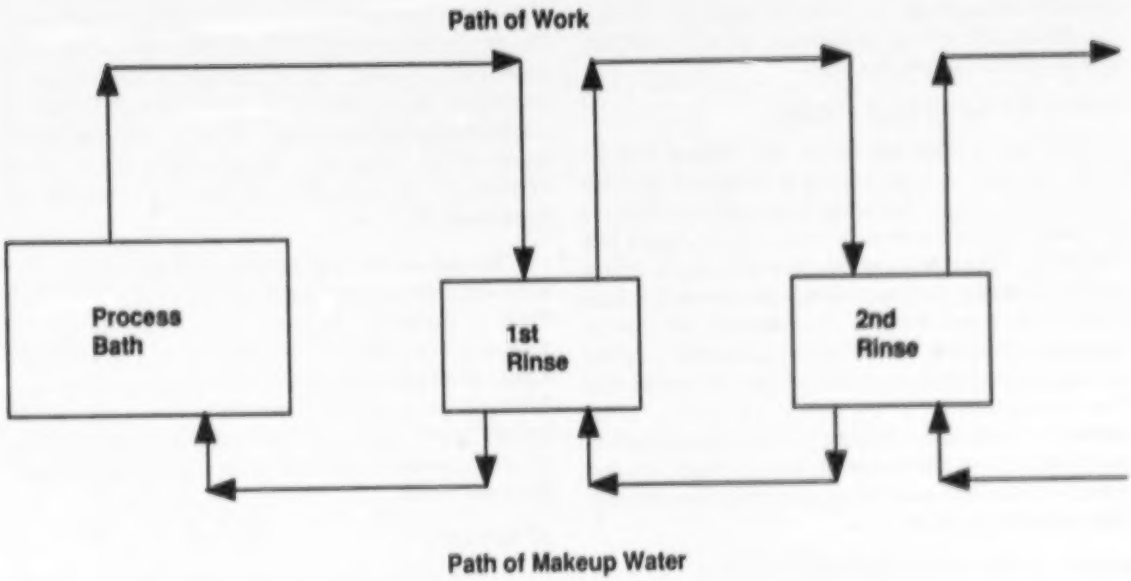

Figure C-2. Multiple Closed Circuit Counterflow Rinse System

contribute to ion-exchange resin use because they are removed during treatment, recycling of rinse waters can reduce spent resin generation and significantly reduced water usage and sewer discharge fees.

Feasibility Analysis Phase

After discussions with Plant C personnel, some of the options discussed in the previous section were selected for investigation of their technical and economic feasibility. The economic analysis was based on the raw material and waste disposal costs provided by the facility personnel and on economic and technical information provided by equipment manufacturers. The measures evaluated in this section include: material substitution, rinse water reduction, drag-out loss reduction, equipment cleanout reduction and rinse water recycling.

MATERIAL SUBSTITUTION

The benefits associated with using recyclable and/or treatable process chemistries will depend on the costs of substitute materials compared with the costs of materials presently used. Also, additional process bath maintenance requirements and treatment costs need to be identified. These costs will depend on the type of substitute material chosen by Plant C.

Savings will include reduced waste disposal costs and material usage costs if the substitute material can be recycled onsite. Plant C generates approximately 250 gallons of waste reflow oil and 500 gallons of waste nitric acid annually. Since waste disposal costs for the waste reflow oil and waste nitric acid are both $100 per 55-gallon drum, which is the average cost for disposing of various liquid hazardous wastes according to circuit board manufacturers, waste disposal cost savings would be approximately $500 per year for spent reflow oil disposal and $1,000 per year for nitric acid waste. Actual savings associated with using recyclable reflow oil and nitric acid will depend on the difference in cost of the substitute materials.

RINSE WATER REDUCTION

The costs associated with converting the plant's four double tank rinse systems into two stage counter-current rinse systems would be minimal. Since the pairs of tanks are already next to each other, the only modifications necessary would be to re-plumb each rinse system. This could be done by Plant C personnel for less than a few hundred dollars. Savings would include reduced water use and sewer fees and reduced ion exchange resin purchases. Since rinse water flow rates, drag-out rates, and rinse

system operating parameters were not available, we could not calculate estimates on savings in water use, sewer fees, and ion exchange resin purchases.

DRAG-OUT LOSS REDUCTION

The use of a bar rail above each process tank for hanging workpiece racks will allow for greater drainage time before rinsing. This could be installed by Plant C's personnel for a few hundred dollars if constructed of 1 inch PVC piping. Other drag-out reduction techniques, such as slowing workpiece rack removal rates and operating process baths at the lowest possible concentration, can also be implemented for little cost. Developing a training program and emphasizing drag-out minimization will require time from management and operations personnel. Since information on drag-out rates and workpiece rack removal and drainage times were not available from Plant C, savings associated with drag-out minimization cannot be quantified prior to implementation.

EQUIPMENT CLEANOUT REDUCTION

Plant C can reduce waste nitric acid generation by using a multiple tank cleaning line. The costs associated with setting up such a system include the cost of additional tanks and the installation labor costs. The costs for setting up a cascade cleaning line would be approximately $350 per tank. Labor costs of $55 an hour for 4 hours would be $220.

The savings associated with a multiple tank plating rack cleaning line include reduced costs for nitric acid purchases and waste acid handling. Plant C now generates approximately 480 gallons of waste nitric acid annually. The consultants visited one plant that used five 30-gallon tanks as a multiple stage cleaning line. That plant generates 30-gallons of waste nitric acid each year. If Plant C could reduce its waste nitric acid generation down to 30 gallons per year, it would achieve an annual savings of approximately $1,400 in nitric acid purchases and $800 in waste disposal costs. This assumes that nitric acid costs $3.10 per gallon and waste disposal costs are $100 per 55-gallon drum.

RINSE WATER RECYCLING

Considerable capital investment may be needed to recycle wastewater for reuse in production. The costs associated with recycling treated wastewater effluent will depend on the level of additional treatment necessary to return the effluent back into the production processes. Other plants that are considering rinse water recycling have indicated that their primary concern is to remove organics from the treated effluent before reusing the water. An activated carbon system to treat the effluent can be used to remove organics from the water. Waste treatment effluent data for the plant were not available from Plant C. Therefore, specific treatment requirements for recycling treated effluent could not be identified. Plant C should investigate the potential for recycling rinse water by characterizing its rinse water effluent, determining the water quality needs for reusing treated effluent, and identifying potential technologies that can be used to treat the effluent for reuse.

The primary savings associated with recycling rinse water are lower water purchase and sewer discharge fees. Plant C generates approximately 3,000 gallons of wastewater each day. Assuming that 90 percent of the water can be recycled, Plant C could reuse approximately 2,700 gallons of water each day. If water and sewer fees are both $0.5 per 750 gallons, Plant C could save approximately $75 each month in water and sewer costs, assuming a 20-day work month.

SUMMARY

The audit of Plant C was performed to identify opportunities for waste reduction. The following hazardous wastes are generated by Plant C each month:

Spent Ion Exchange Resin - Approximately 100 gallons

Copper Sulfate Crystals- Undetermined

Nitric Acid Waste- Approximately 40 gallons

Reflow Oil- Approximately 20 gallons

The audit provided information that was used to identify several waste reduction techniques that may be feasible for Plant C to implement. The following waste reduction opportunities were identified:

- Use alternative reflow oil and electroplating rack stripper materials that can be recycled or treated when they are spent instead of chemistries that currently are containerized for off-site disposal.
- Aggressively pursue drag-out reduction by developing operational procedures and training personnel to slowly remove workpiece racks and increase drainage time prior to rinsing.
- Convert the four double tank rinse systems into two-stage counter-current rinse systems.
- Install a multiple stage electroplating rack cleaning line to reduce nitric acid waste generation.
- Recycle treated effluent for reuse in the production process.

APPENDIX B
WHERE TO GET HELP
FURTHER INFORMATION ON POLLUTION PREVENTION

Additional information on source reduction, reuse and recycling approaches to pollution prevention is available in EPA reports listed in this section, and through state programs (listed below) that offer technical and/or financial assistance in the areas of pollution prevention and treatment.

In addition, waste exchanges have been established in some areas of the U.S. to put waste generators in contact with potential users of the waste. Four waste exchanges are listed below. Finally, EPA's regional offices are listed.

EPA REPORTS ON WASTE MINIMIZATION

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Corrosive and Heavy Metal Waste Minimization Audit at a Specialty Steel Manufacturing Complex." Executive Summary.*

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste for Parts Cleaning and from Electronic Capacitor Manufacturing Operation." Executive Summary.*

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Minimization of Cyanide Wastes from Electroplating Operations." Executive Summary.*

U.S. Environmental Protection Agency. Report to Congress: Waste Minimization, Vols. I and II. EPA/530-SW-86-033 and -034 (Washington, D.C.: U.S. EPA, 1986).**

U.S. Environmental Protection Agency. Waste Minimization - Issues and Options, Vols. I-III EPA/530-SW-86-041 through -043. (Washington, D.C.: U.S. EPA, 1986).**

* Executive Summary available from EPA, WMDDRD, RREL, 26 West Martin Luther King Drive, Cincinnati, OH, 45268; full report available from the National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, VA 22161.

** Available from the National Technical Information Service as a five-volume set, NTIS No. PB-87-114-328.

WASTE REDUCTION TECHNICAL/ FINANCIAL ASSISTANCE PROGRAMS

The EPA's Office of Solid Waste and Emergency Response has set up a telephone call-in service to answer questions regarding RCRA and Superfund (CERCLA):

(800) 242-9346 (outside the District of Columbia)

(202) 382-3000 (in the District of Columbia)

The following states have programs that offer technical and/or financial assistance in the areas of waste minimization and treatment.

Alabama
Hazardous Material Management and Resources Recovery Program
University of Alabama
P.O. Box 6373
Tuscaloosa, AL 35487-6373
(205) 348-8401

Alaska
Alaska Health Project
Waste Reduction Assistance Program
431 West Seventh Avenue, Suite 101
Anchorage, AK 99501
(907) 276-2864

Arkansas
Arkansas Industrial Development Commission
One State Capitol Mall
Little Rock, AR 72201
(501) 371-1370

California
Alternative Technology Section
Toxic Substances Control Division
California State Department of Health Service
714/744 P Street
Sacramento, CA 94234-7320
(916) 324-1807

Connecticut
Connecticut Hazardous Waste Management Service
Suite 360
900 Asylum Avenue
Hartford, CT 06105
(203) 244-2007

Connecticut Department of Economic Development
210 Washington Street
Hartford, CT 06106
(203) 566-7196

Georgia
Hazardous Waste Technical Assistance Program
Georgia Institute of Technology
Georgia Technical Research Institute
Environmental Health and Safety Division
O'Keefe Building, Room 027
Atlanta, GA 30332
(404) 894-3806

Environmental Protection Division
Georgia Department of Natural Resources
Floyd Towers East, Suite 1154
205 Butler Street
Atlanta, GA 30334
(404) 656-2833

Illinois
Hazardous Waste Research and Information Center
Illinois Department of Energy of Energy and Natural Resources
1808 Woodfield Drive
Savoy, IL 61874
(217) 333-8940

Illinois Waste Elimination Research Center
Pritzker Department of Environmental Engineering
Alumni Building, Room 102
Illinois Institute of Technology
3200 South Federal Street
Chicago, IL 60616
(313) 567-3535

Indiana
Environmental Management and Education Program
Young Graduate House, Room 120
Purdue University
West Lafayette, IN 47907
(317) 494-5036

Indiana Department of Environmental Management
Office of Technical Assistance
P.O. Box 6015
105 South Meridian Street
Indianapolis, IN 46206-6015
(317) 232-8172

Iowa
Center for Industrial Research and Service
205 Engineering Annex
Iowa State University
Ames, IA 50011
(515) 294-3420

Iowa Department of Natural Resources
Air Quality and Solid Waste Protection Bureau
Wallace State Office Building
900 East Grand Avenue
Des Moines, IA 50319-0034
(515) 281-8690

Kansas
Bureau of Waste Management
Department of Health and Environment
Forbes Field, Building 730
Topeka, KS 66620
(913) 269-1607

Kentucky
Division of Waste Management
Natural Resources and Environmental Protection Cabinet
18 Reilly Road
Frankfort, KY 40601
(502) 564-6716

Louisiana
Department of Environmental Quality
Office of Solid and Hazardous Waste
P.O. Box 44307
Baton Rouge, LA 70804
(504) 342-1354

Maryland
Maryland Hazardous Waste Facilities Siting Board
60 West Street, Suite 200 A
Annapolis, MD 21401
(301) 974-3432

Maryland Environmental Service
2020 Industrial Drive
Annapolis, MD 21401
(301) 269-3291
(800) 492-9188 (in Maryland)

Massachusetts
Office of Safe Waste Management
Department of Environmental Management
100 Cambridge Street, Room 1094
Boston, MA 02202
(617) 727-3260

Source Reduction Program
Massachusetts Department of Environmental Quality Engineering
1 Winter Street
Boston, MA 02108
(617) 292-5982

Michigan
Resource Recovery Section
Department of Natural Resources
P.O. Box 30028
Lansing, MI 48909
(517) 373-0540

Minnesota
Minnesota Pollution Control Agency
Solid and Hazardous Waste Division
520 Lafayette Road
St. Paul, MN 55155
(612) 296-6300

Minnesota Technical Assistance Program
W-140 Boynton Health Service
University of Minnesota
Minneapolis, MN 55455
(612) 625-9677

(800) 247-0015 (in Minnesota)
Minnesota Waste Management Board
123 Thorson Center
7323 Fifty-Eighth Avenue North
Crystal, MN 55428
(612) 536-0816

Missouri
State Environmental Improvement and Energy Resources Agency
P.O. Box 744
Jefferson City, MO 65102
(314) 751-4919

New Jersey
New Jersey Hazardous Waste Facilities Siting Commission
Room 614
28 West State Street
Trenton, NJ 08608
(609) 292-1459
(609) 292-1026

Hazardous Waste Advisement Program
Bureau of Regulation and Classification
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625

Risk Reduction Unit
Office of Science and Research
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625

New York
New York State Environmental Facilities Corporation
50 Wolf Road
Albany, NY 12205
(518) 457-3273

North Carolina
Pollution Prevention Pays Program
Department of Natural Resources and Community Development
P.O. Box 27687
512 North Salisbury Street
Raleigh, NC 27611
(919) 733-7015

Governor's Waste Management Board
325 North Salisbury Street
Raleigh, NC 27611
(919) 733-9020

Technical Assistance Unit
Solid and Hazardous Waste Management Branch
North Carolina Department of Human Resources
P.O. Box 2091
306 North Wilmington Street
Releigh, NC 27602
(919) 733-2178

Ohio
Division of Solid and Hazardous Waste Management
Ohio Environmental Protection Agency
P.O. Box 1049
1800 WaterMark Drive
Columbus, OH 43266-1049
(614) 481-7200

Ohio Technology Transfer Organization
Suite 200
65 East State Street
Columbus, OH 43266-0330
(614) 466-4286

Oklahoma
Industrial Waste Elimination Program
Oklahoma State Department of Health
P.O. Box 53551
Oklahoma City, OK 73152
(405) 271-7353

Oregon
Oregon Hazardous Waste Reduction Program
Department of Environmental Quality
811 Southwest Sixth Avenue
Portland, OR 97204
(503) 229-5913

Pennsylvania
Pennsylvania Technical Assistance Program
501 F. Orvis Keller Building
University Park, PA 16802
(814) 865-0427

Center of Hazardous Material Research
320 William Pitt Way
Pittsburgh, PA 15238
(412) 826-5320

Bureau of Waste Management
Pennsylvania Department of
Environmental Resources
P.O. Box 2063
Fulton Building
3rd and Locust Streets
Harrisburg, PA 17120
(717) 787-6239

Rhode Island
Ocean State Cleanup and Recycling Program
Rhode Island Department of Environmental Management
9 Hayes Street
Providence, RI 02908-5003
(401) 277-3434
(800) 253-2674 (in Rhode Island)

Center for Environmental Studies
Brown University
P.O. Box 1943
135 Angell Street
Providence, RI 02912
(401) 863-3449

Tennessee
Center for Industrial Services
102 Alumni Hall
University of Tennessee
Knoxville, TN 37996
(615) 974-2456

Virginia
Office of Policy and Planning
Virginia Department of Waste Management
11th Floor, Monroe Building
101 North 14th Street
Richmond, VA 23219
(804) 225-2667

Washington
Hazardous Waste Section
Mail Stop PV-11
Washington Department of Ecology
Olympia, WA 98504-8711
(206) 459-6322

Wisconsin
Bureau of Solid Waste Management
Wisconsin Department of Natural Resources
P.O. Box 7921
101 South Webster Street
Madison, WI 53707
(608)267-3763

Wyoming
Solid Waste Management Program
Wyoming Department of Environmental Quality
Herchler Building, 4th Floor, West Wing
122 West 25th Street
Cheyenne, WY 82002
(307) 777-7752

WASTE EXCHANGES

Northeast Industrial Exchange
90 Presidential Plaza, Syracuse, NY 13202
(315) 422-6572

Southern Waste Information Exchange
P.O. Box 6487, Tallahassee, FL 32313
(904) 644-5516

California Waste Exchange
Department of Health Services
Toxic Substances Control Division
Alternative Technology & Policy Development Section
714 P Street
Sacramento, CA 95814
(916) 324-1807

U.S. EPA REGIONAL OFFICES

Region 1 (VT, NH, ME, MA, CT, RI)
John F. Kennedy Federal Building
Boston, MA 02203
(617) 565-3715

Region 2 (NY, NJ)
26 Federal Plaza
New York, NY 10278
(212) 264-2525

Region 3 (PA, DE, MD, WV, VA)
841 Chestnut Street
Philadelphia, PA 19107
(215) 597-9800

Region 4 (KY, TN, NC, SC, GA, FL, AL, MS)
345 Courtland Street, NE
Atlanta, GA 30365
(404) 347-4727

Region 5 (WI, MN, MI, IL, IN, OH)
230 South Dearborn Street
Chicago, IL 60604
(312) 353-2000

Region 6 (NM, OK, AR, LA, TX)
1445 Ross Avenue
Dallas, TX 75202
(214) 655-6444

Region 7 (NE, KS, MO, IA)
756 Minnesota Avenue
Kansas City, KS 66101
(913) 236-2800

Region 8 (MT, ND, SD, WY, UT, CO)
999 18th Street
Denver, CO 80202-2405
(303) 293-1603

Region 9 (CA, NV, AZ, HI)
215 Fremont Street
San Francisco, CA 94105
(415) 974-8071

Region 10 (AK, WA, OR, ID)
1200 Sixth Avenue
Seattle, WA 98101
(206) 442-5810

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